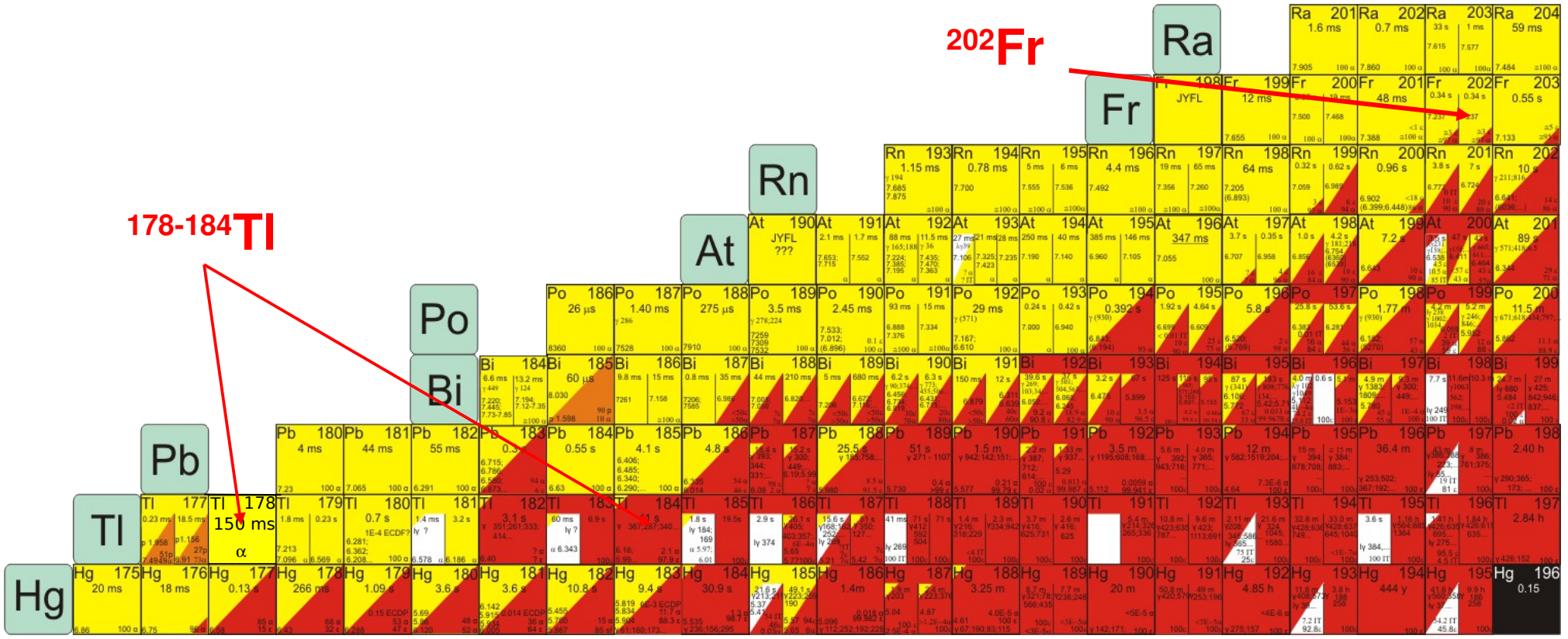
Valentina Liberati
University of the West of Scotland
Paisley, Scotland

On behalf of IS466 Collaboration and the ISOLDE collaboration

β delayed fission studies in the lead region



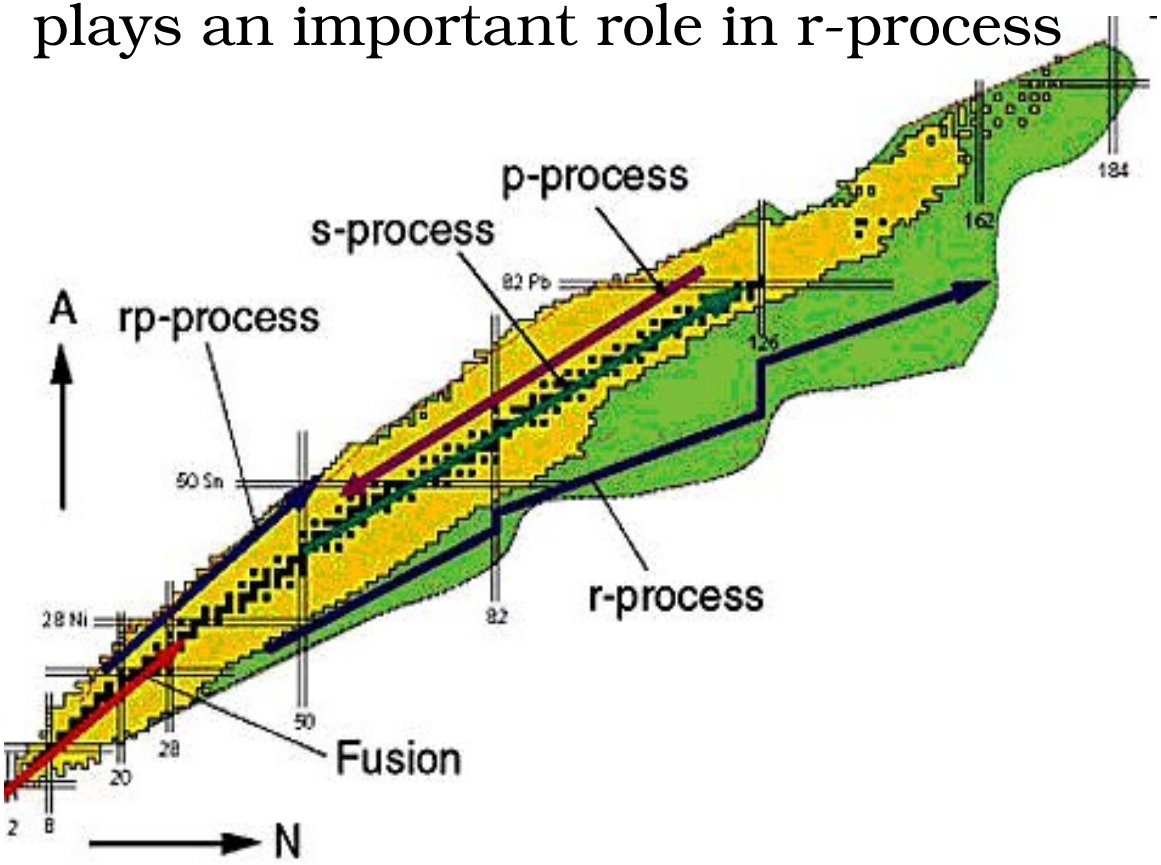
Contents ..

- *Motivation – fission and r-process*
- *B delayed fission – general properties*
- *IS466 (-II) experiments @ ISOLDE -*
  - ^{180}Tl
  - ^{178}Tl
  - ^{202}Fr
- *βDF@GSI*

Fission and r-process ..

- Fission

(spontaneus fission, n-induced fission and β delayed fission) plays an important role in r-process



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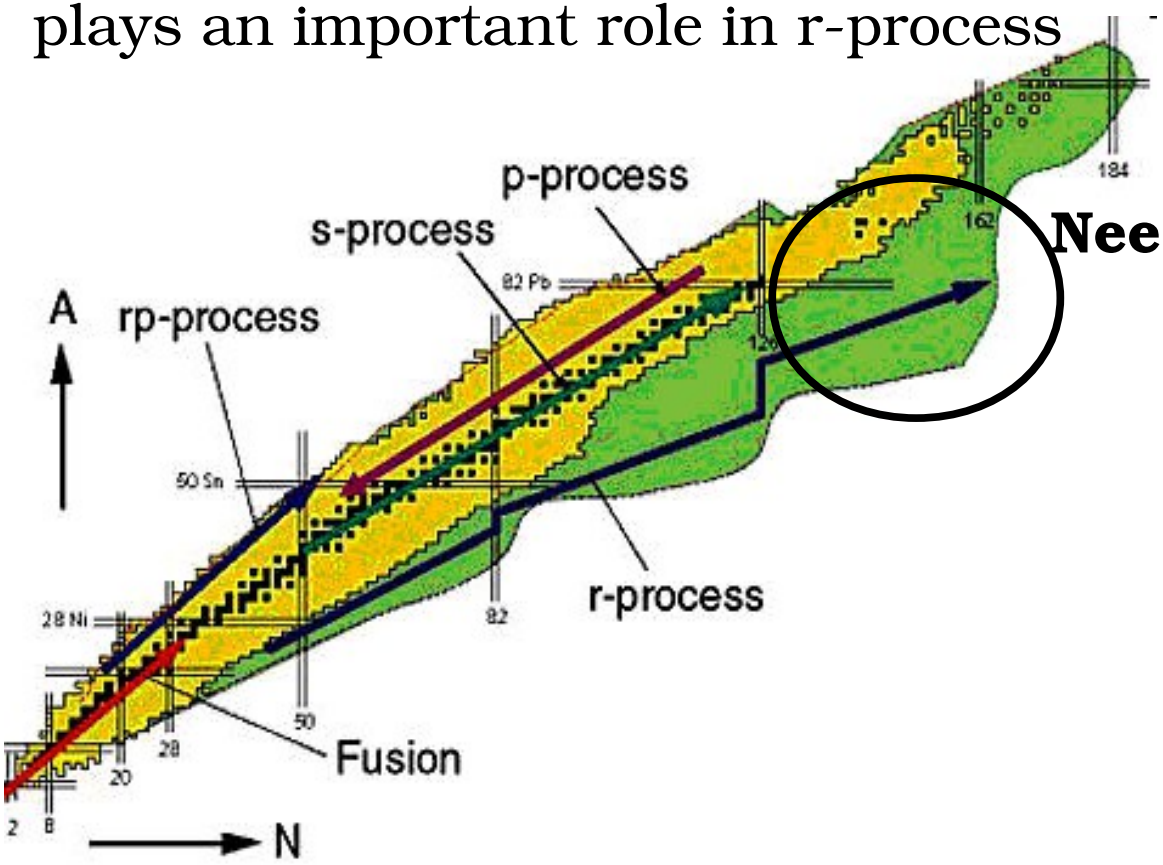

Need data for very exotic nuclei

Fission and r-process ..

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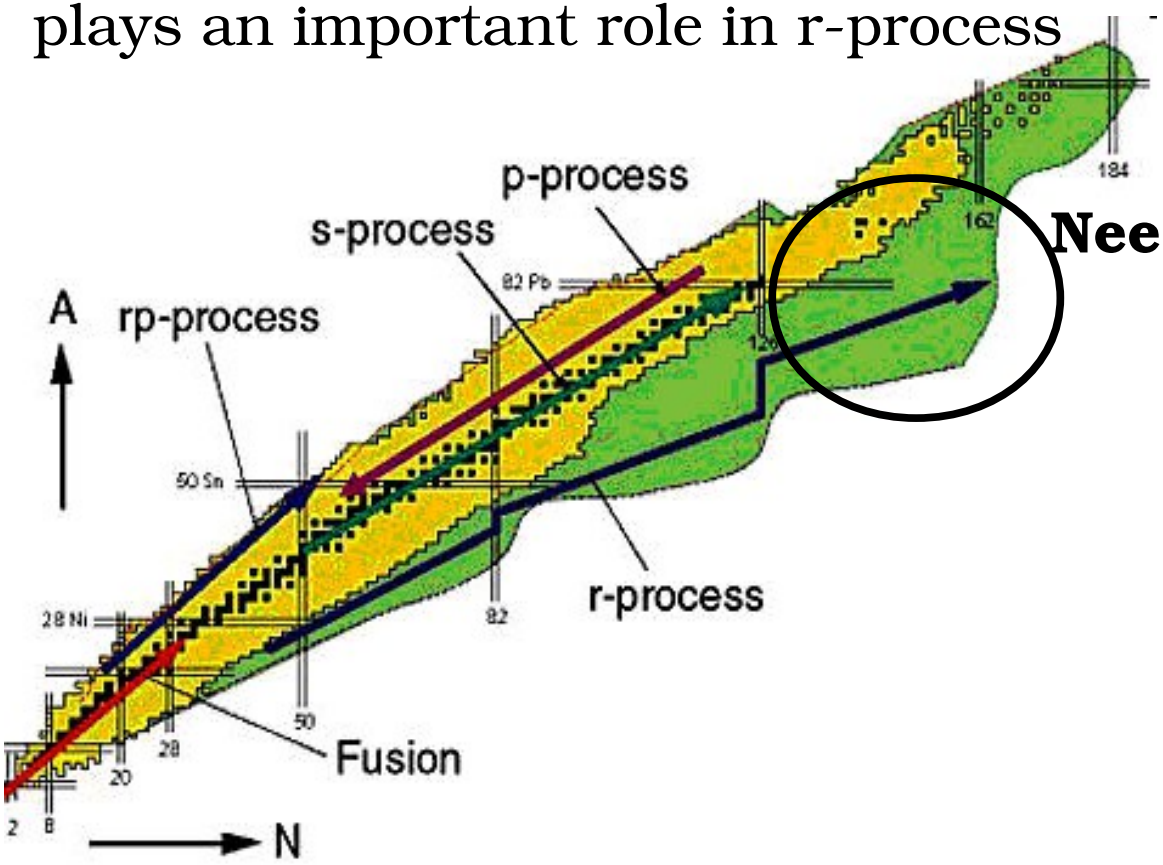
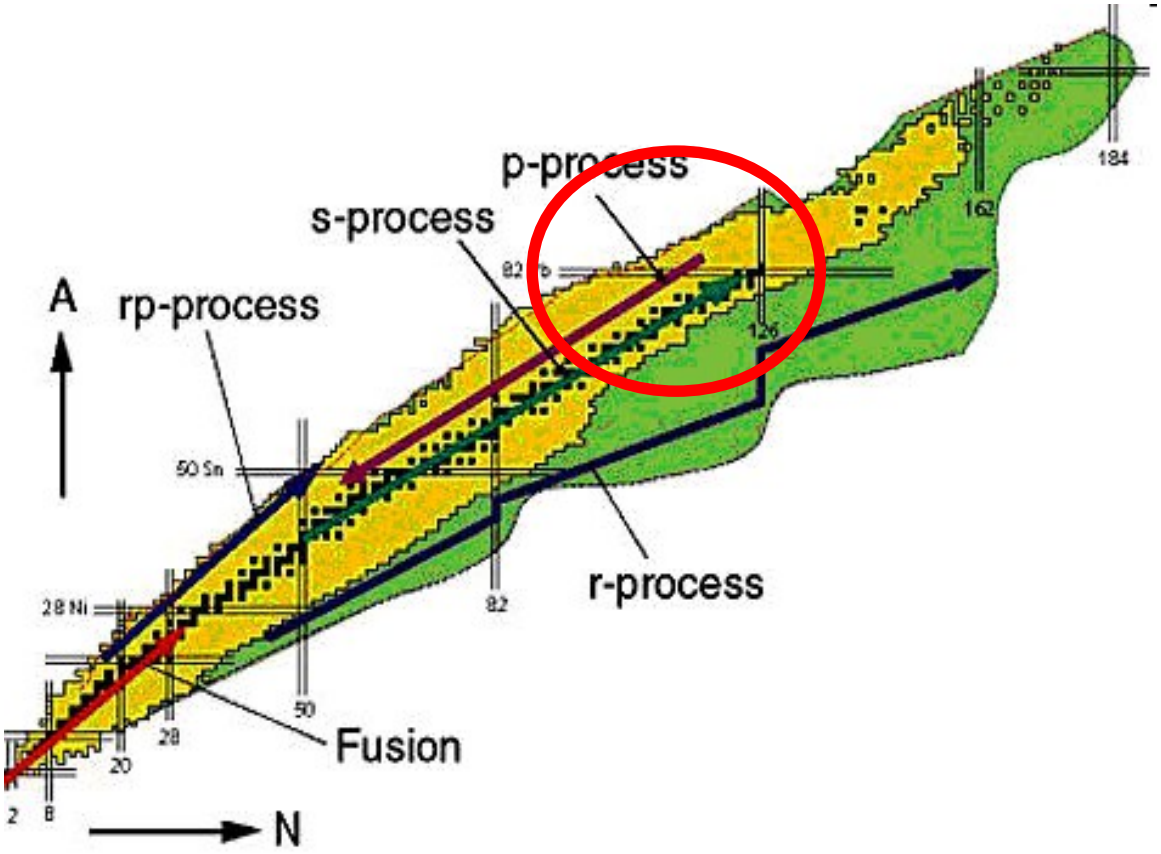


Need data for very exotic nuclei

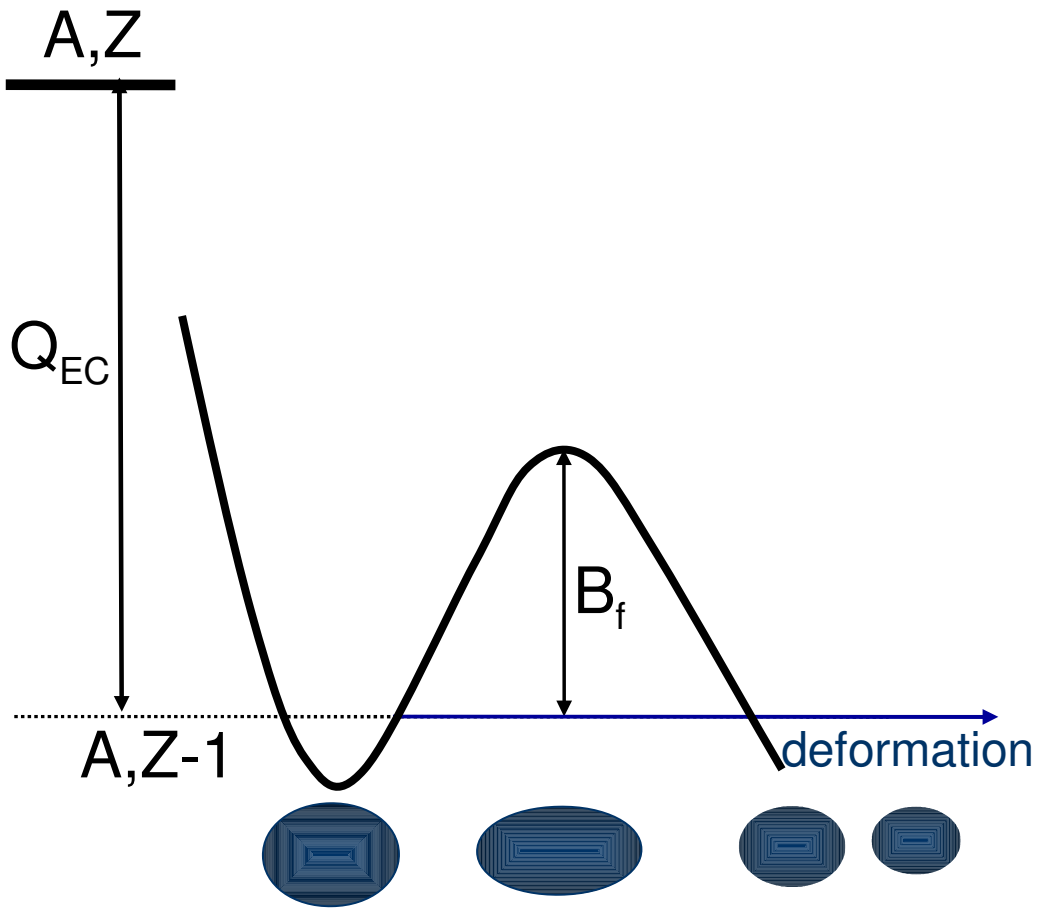
Unfortunately, so exotic nuclei are not presently accessible by available techniques!

Fission and r-process ..



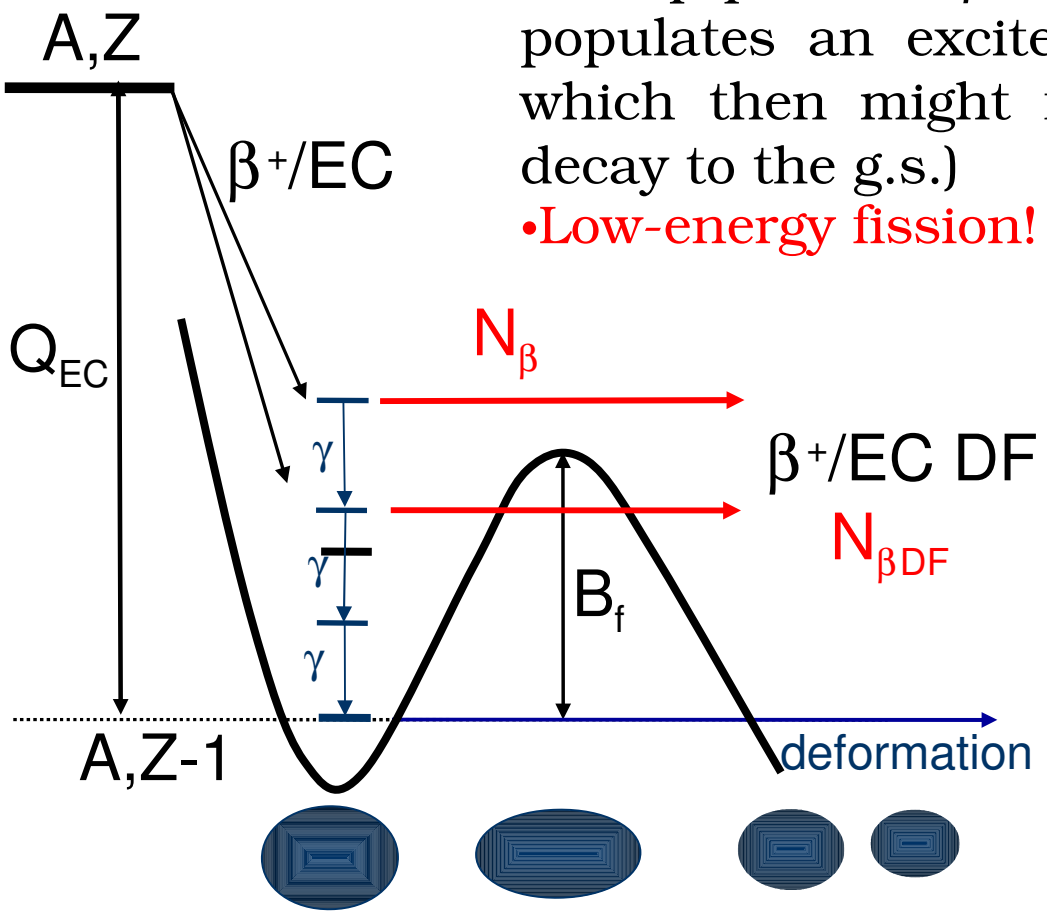
- That is why the underlying mechanisms and properties of beta-delayed fission (and of low-energy fission in general) have to be investigated by using alternative approaches and in other regions of the Nuclear Chart.
- According to semi-empirical estimates, the neutron-deficient nuclei in the U and Pb regions provide such a possibility via the beta-delayed fission decay

β delayed fission..



β delayed fission..

- Discovered in 1966 @Dubna ^{232,234}Am
- 2 step process: β^+/EC decay of a parent (A,Z) nucleus populates an excited state in the (A,Z-1) daughter, which then might fission (in competition with the γ decay to the g.s.)
- Low-energy fission! ($E^* <= Q_{EC}$)



βDF branch

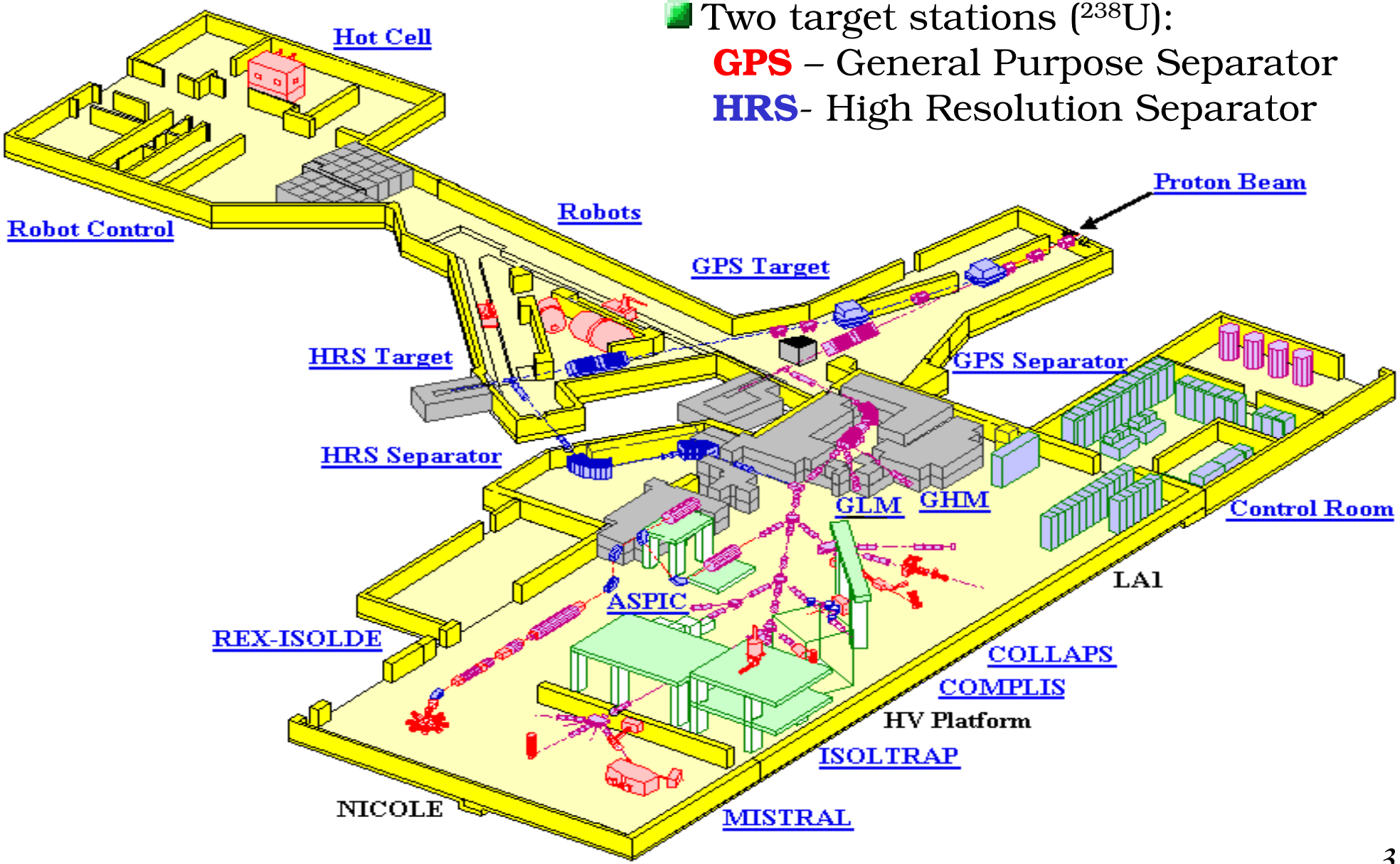
$$P_{\beta DF} = \frac{N_{\beta DF}}{N_\beta}$$

$P_{\beta DF}$ depends strongly on:

- Q_{EC} of the parent
- B_f of the daughter
- Actually, Q_{EC}-B_f is important

ISOLDE@CERN..

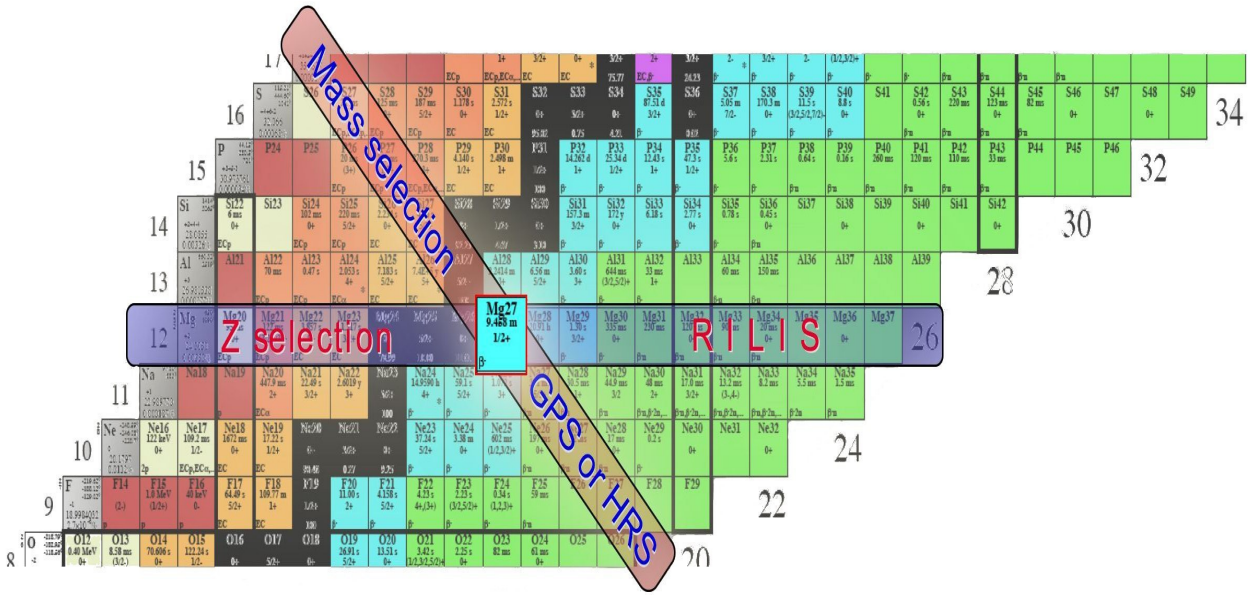
- Proton beam 1.4 μA, 1.4 GeV from PSB
- Two target stations (^{238}U):
  - **GPS** – General Purpose Separator
  - **HRS**- High Resolution Separator



Isotope Selection..

- Hundreds of different isotopes are produced.

A highly selective method is required to achieve a pure beam



Use mass separator to select mass A: => ISOLDE

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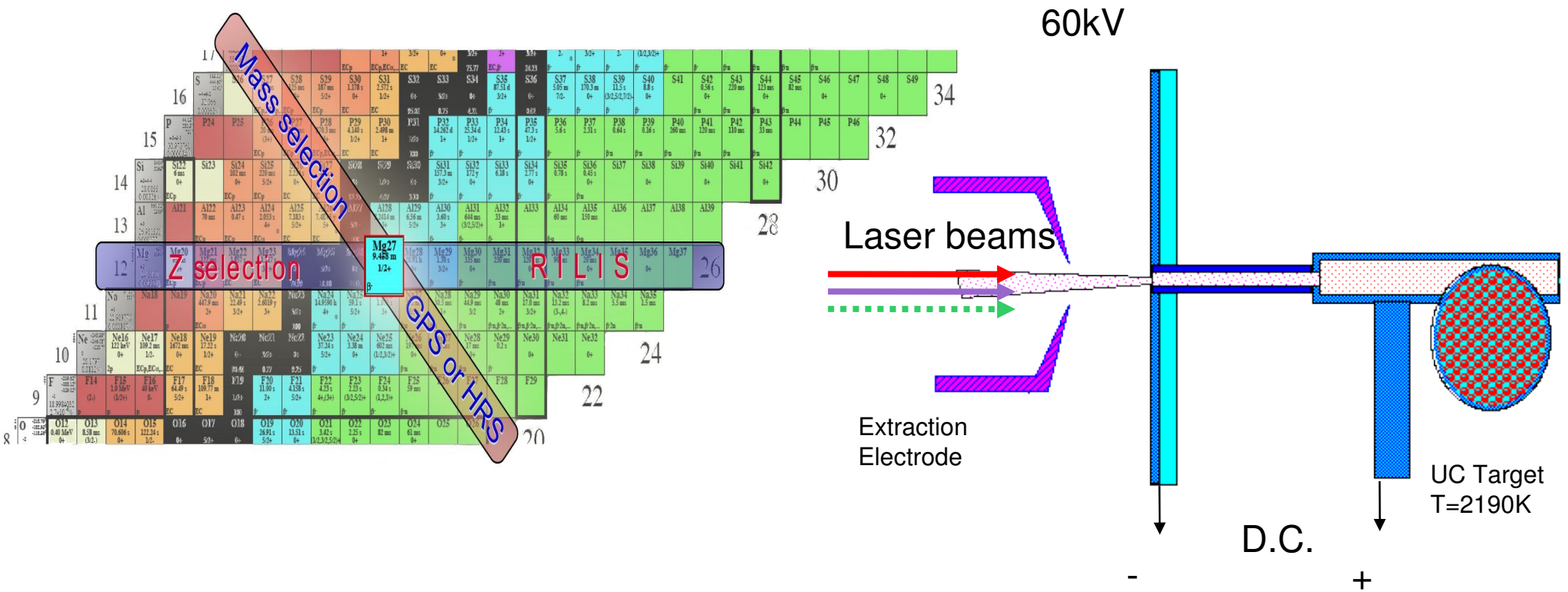
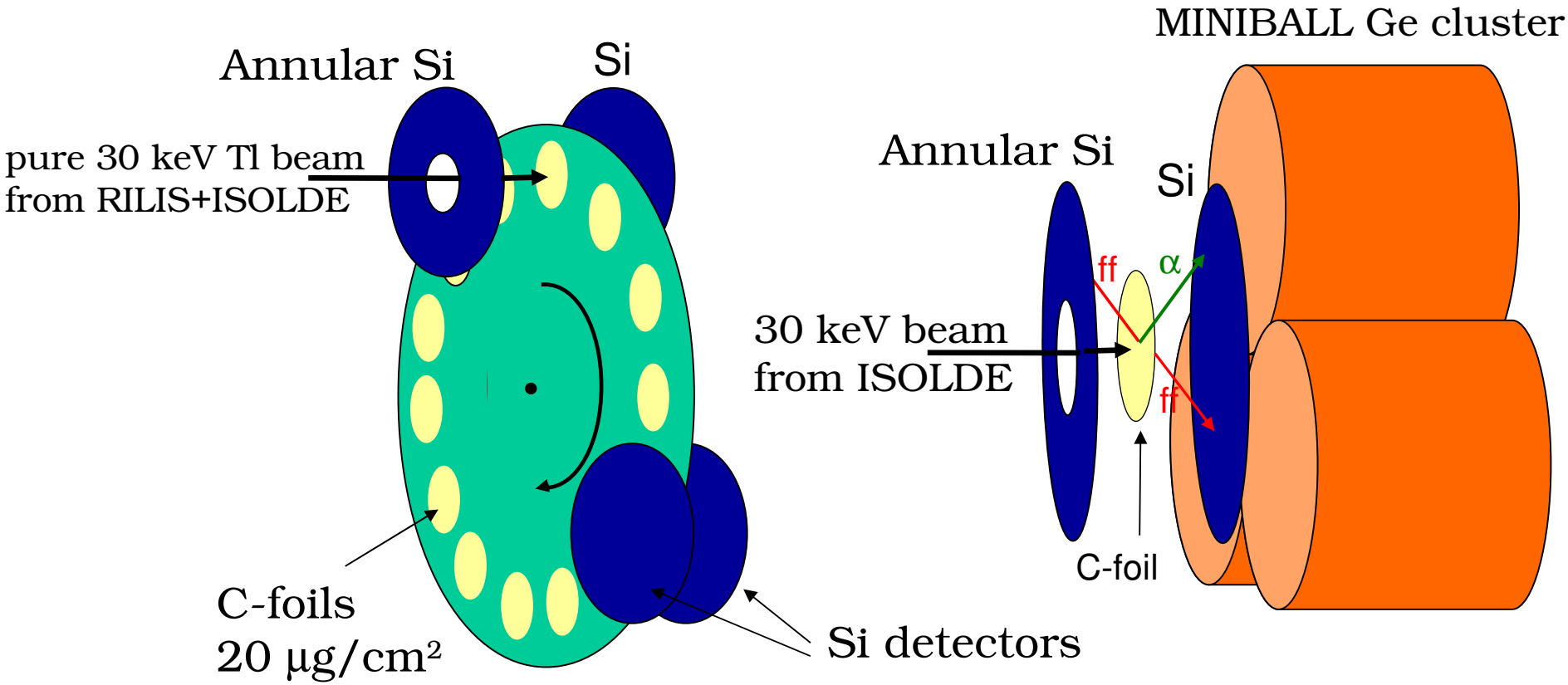
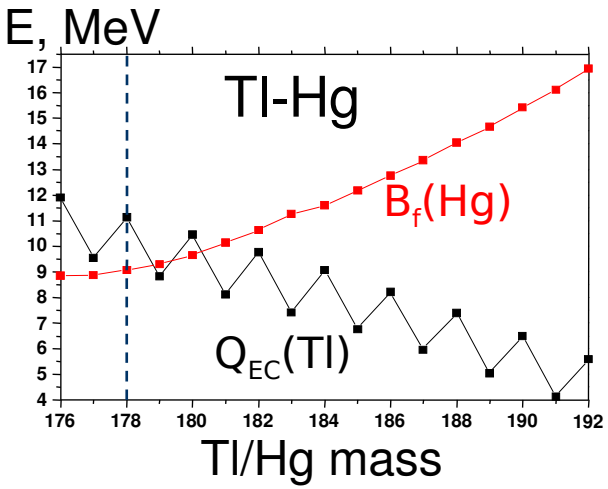


Use mass separator to select mass A: => ISOLDE
Use laser Ion Source to select Z: =>RILIS

RILIS&ISOLDE can provide a unique A and Z identification

Experiment IS466-* Setup ..





Setup: Si detectors from both sides of the C-foil

- Simple setup & DAQ: 4 PIPS (1 of them – annular)
- Large geometrical efficiency (up to 80%)
- 2 fold fission fragment coincidences
- ff-gamma coincidences
- Digital electronics (5 DGF modules)

^{180}Tl from IS466..

A New Type of Asymmetric Fission in Proton-Rich Nuclei

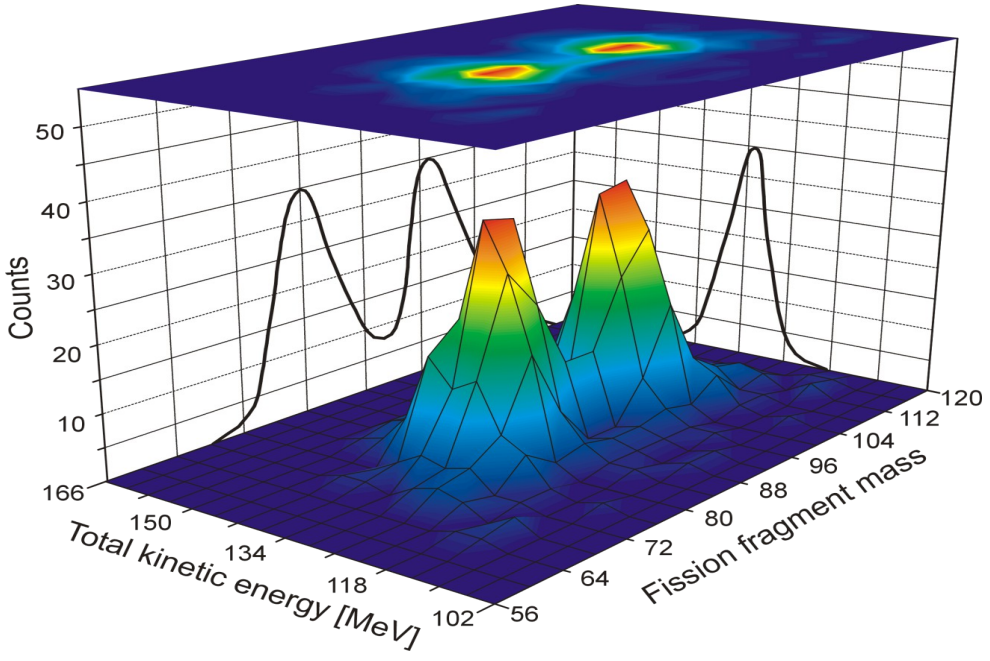
A.N. Andreyev[1,2], J. Elseviers[1], M. Huyse[1], P. Van Duppen[1], S. Antalic[3], A. Barzakh[4], N. Bree[1], T.E. Cocolios[1], V. F. Comas[5], J. Diriken[1], D. Fedorov[4], V. Fedosseev[6], S. Franchoo[7], J.A. Heredia[5], O. Ivanov[1], U. Köster[8], B. A. Marsh[6], K. Nishio[9], R.D. Page[10], N. Patronis[1,11], M. Seliverstov[1,6], I. Tsekhanovich[12,17], P. Van den Bergh[1], J. Van De Walle[6], M. Venhart[1,3], S. Vermote[13], M. Veselsky[14], C. Wagemans[13], T. Ichikawa[15], A. Iwamoto[9], P. Möller[16], A.J. Sierk[16]

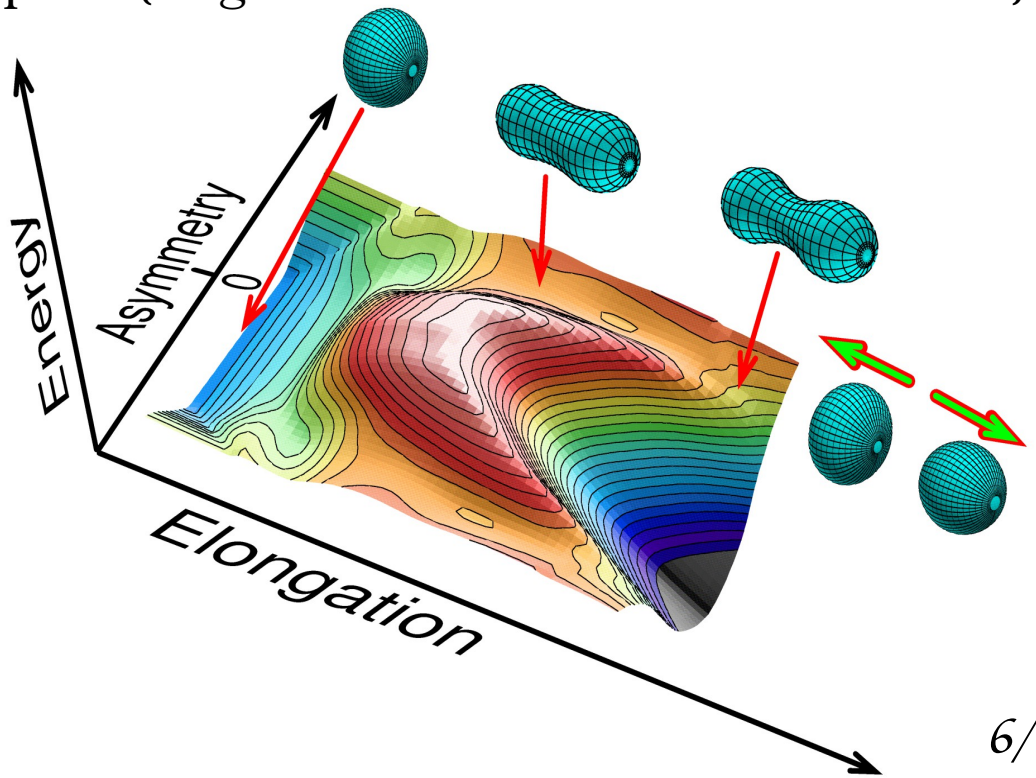
[1] *Instituut voor Kern- en Stralingsfysica, K.U. Leuven, University of Leuven, B-3001 Leuven, Belgium*

[2] *School of Engineering, University of the West of Scotland, Paisley, PA1 2BE, UK and the Scottish Universities Physics Alliance (SUPA)*

http://www.nature.com/news/2010/101201/full/news.2010.642.html

"Mercury serves up a nuclear surprise"(Eugenie Samuel Reich-Nature News)





Experiment IS466-II ..

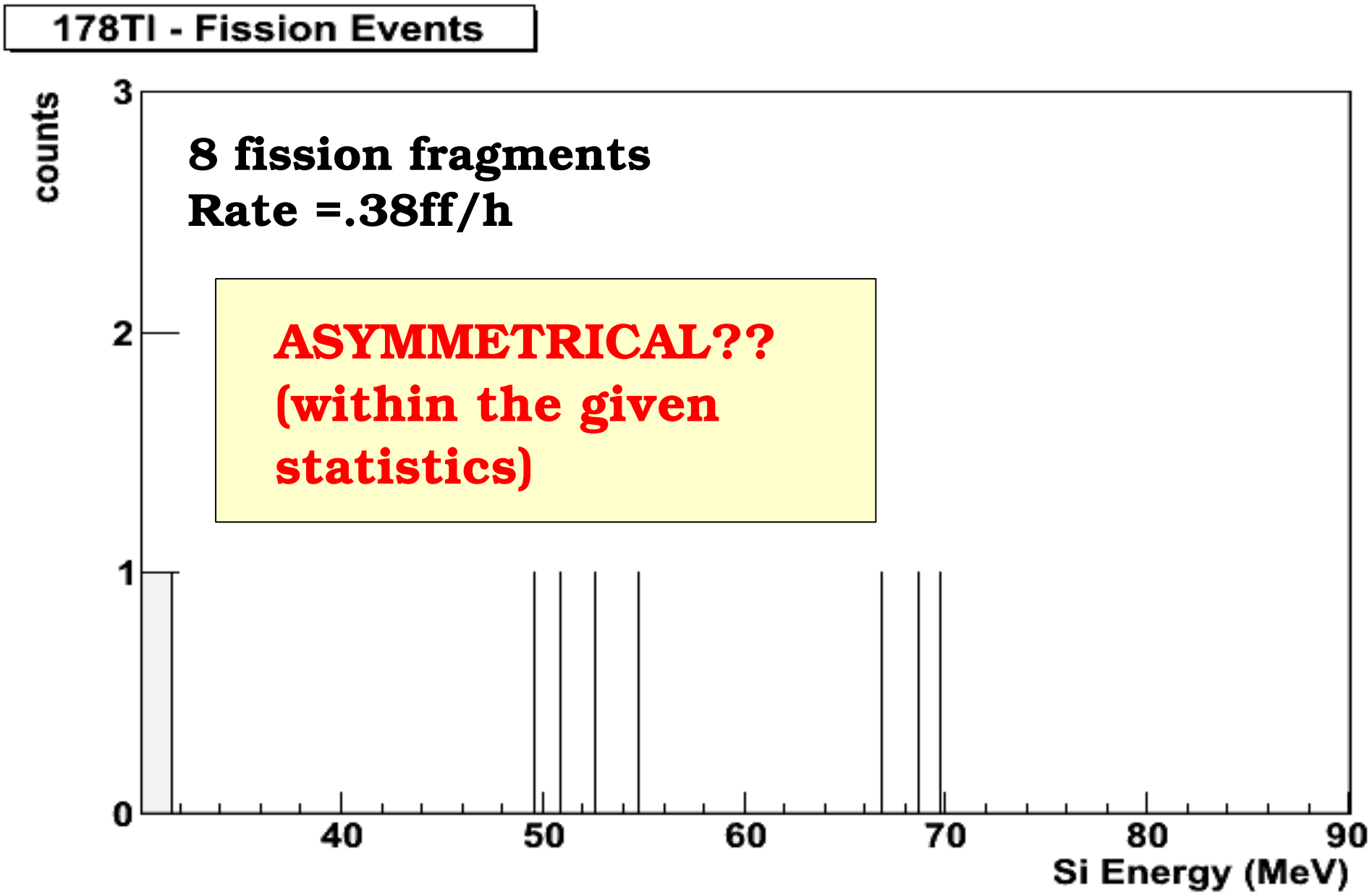
In view of the very successful IS466 run : research extended to **lighter and heavier neighbors of ^{180}Tl.**

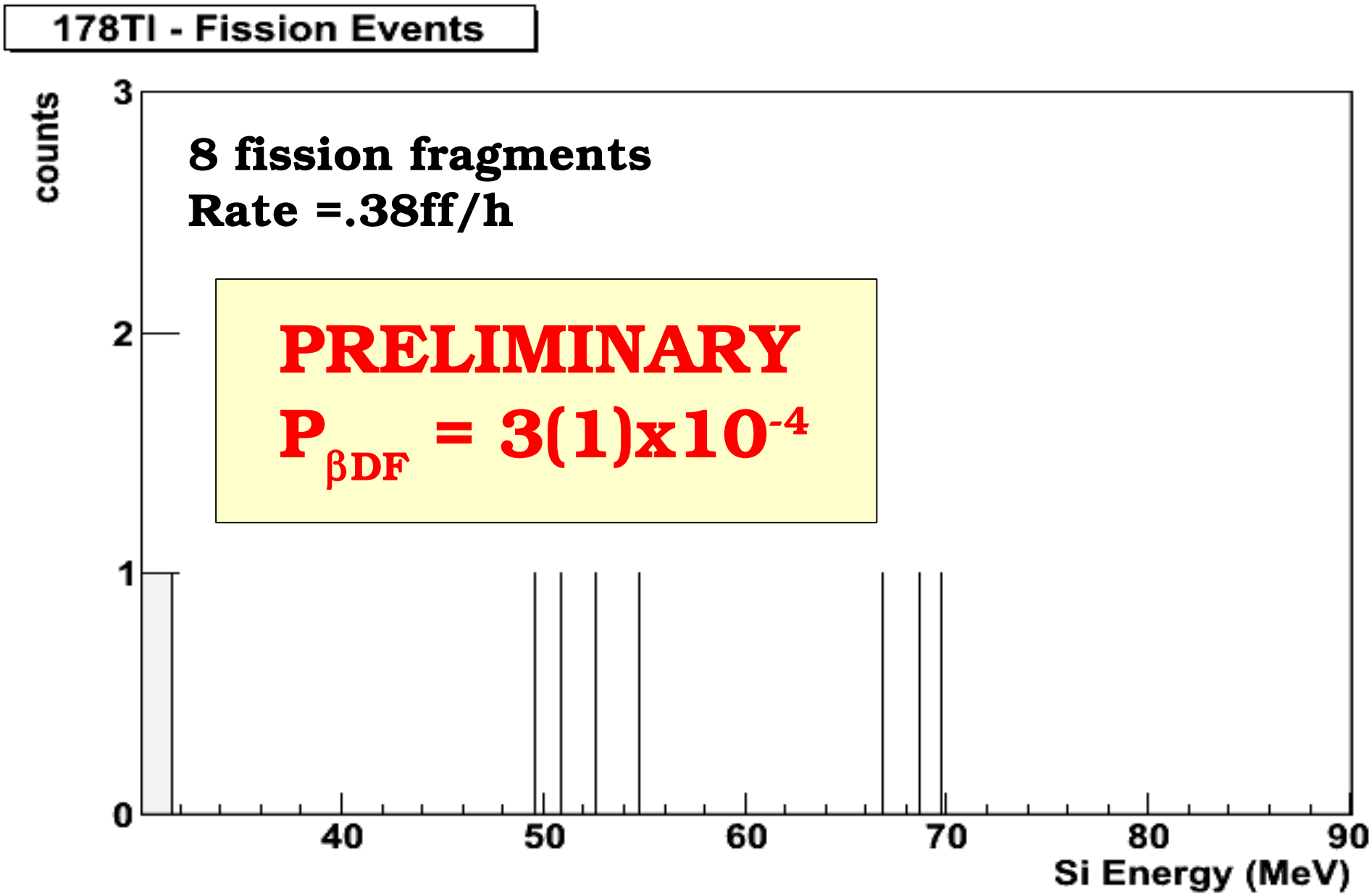
^{178}Tl	**^{182}Tl**
^{180}Tl	^{183}Tl
^{181}Tl	^{184}Tl
^{202}Fr	

- **ISOTOPE SHIFT** and **HYPERFINE STRUCTURE** measurement performed for the **red** nuclei

This will allow deducing properties of the nuclei, i.e, radius, moments,..

(Relative data currently under analysis)


178Tl - Fission Events
counts
3
2
1
0
8 fission fragments
Rate =.38ff/h
ASYMMETRICAL??
(within the given
statistics)
40
50
60
70
80
90
Si Energy (MeV)


178Tl - Fission Events
counts
3
2
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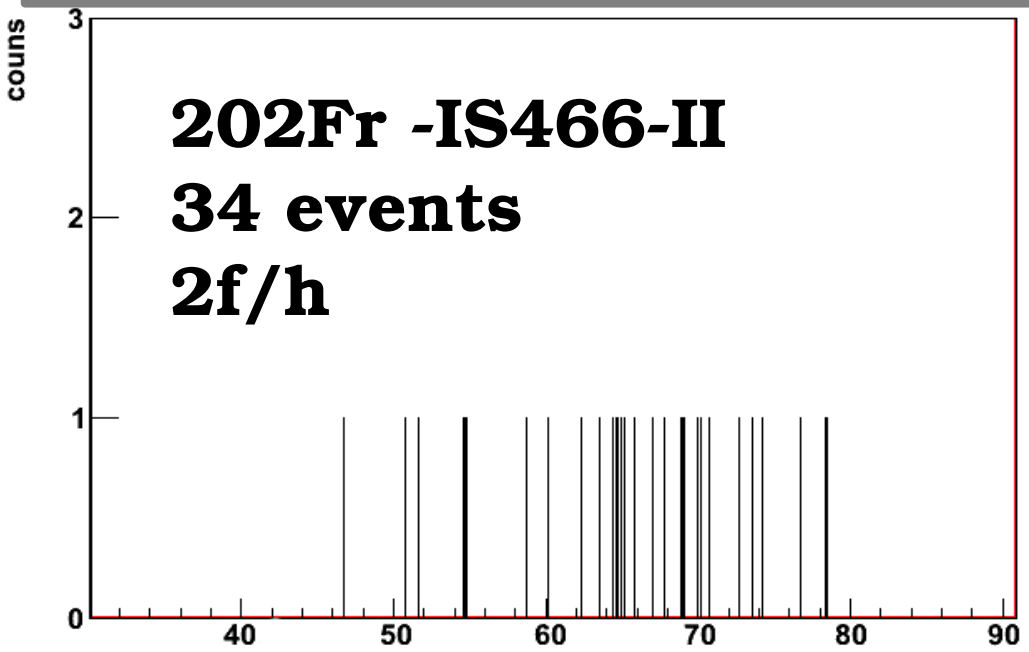
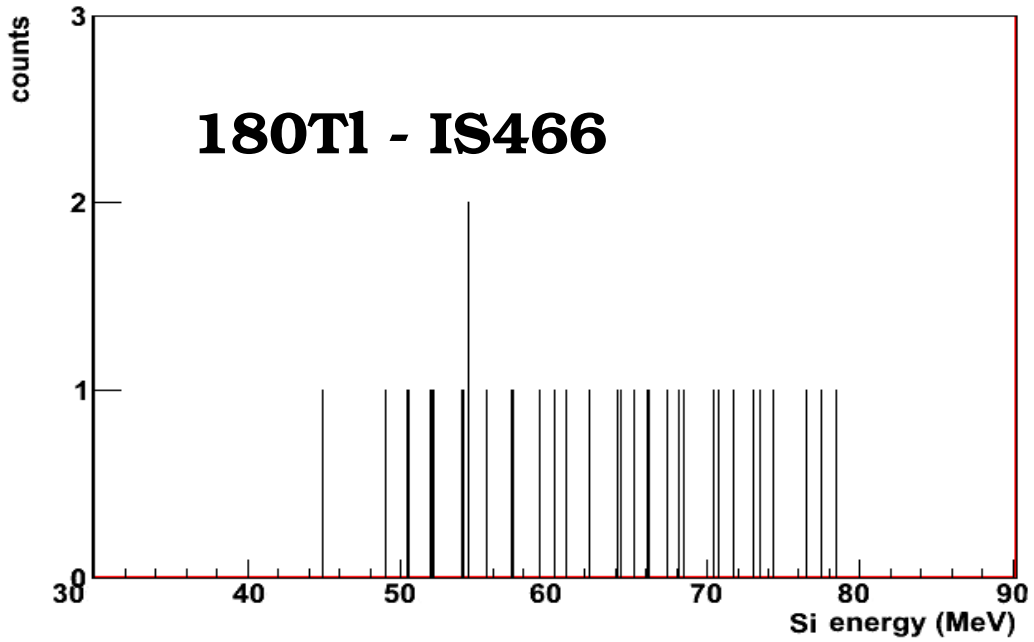
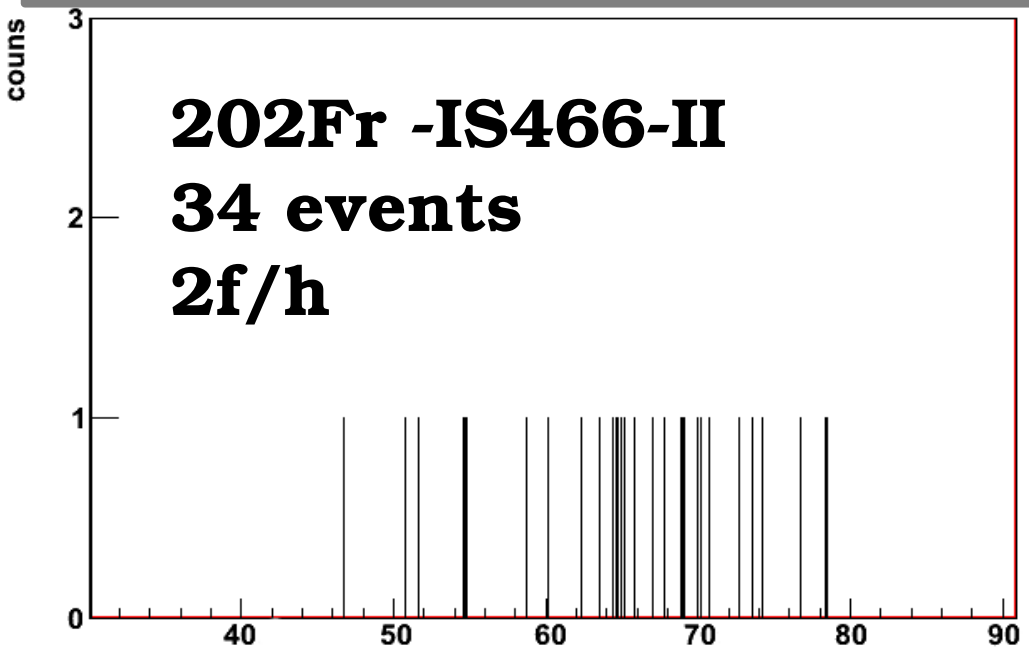
8 fission fragments
Rate =.38ff/h
PRELIMINARY
$P_{\beta DF} = 3(1)x10^{-4}$
40
50
60
70
80
90
Si Energy (MeV)

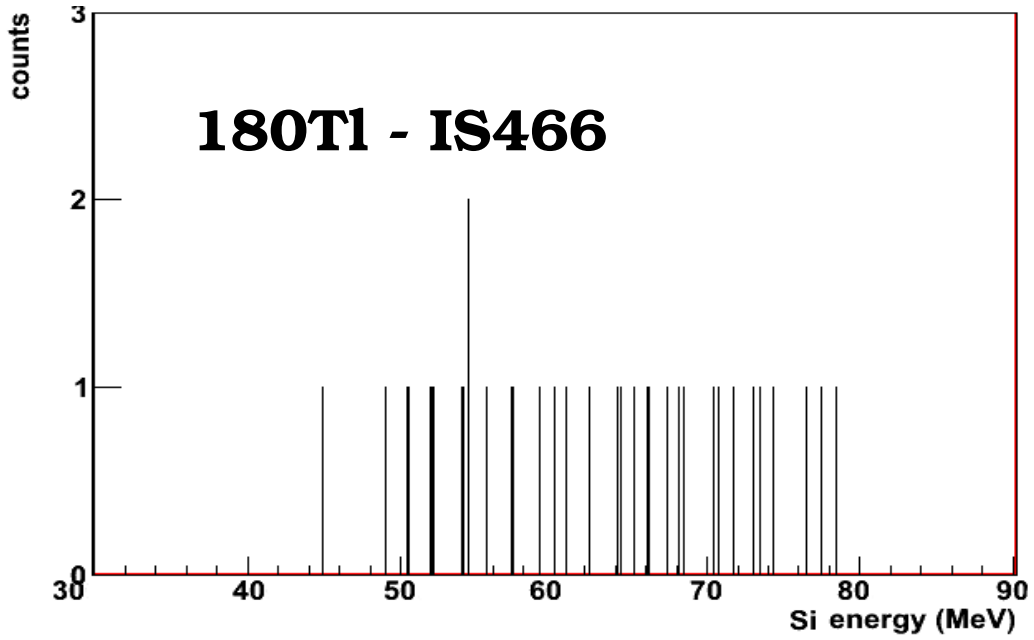
^{202}Fr - Fission ..





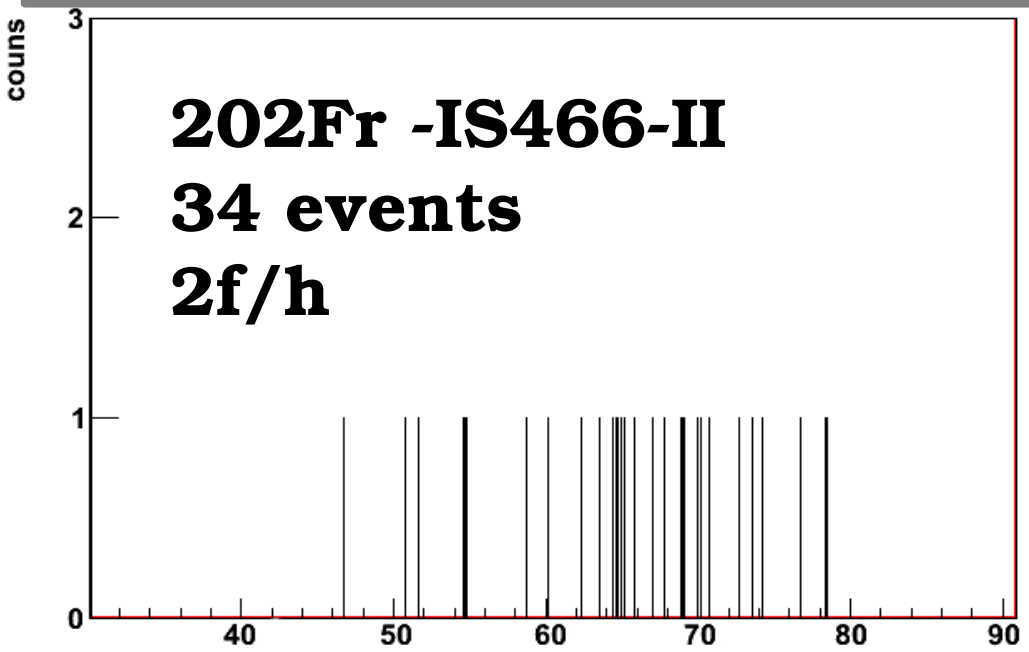
^{202}Fr - Fission ..

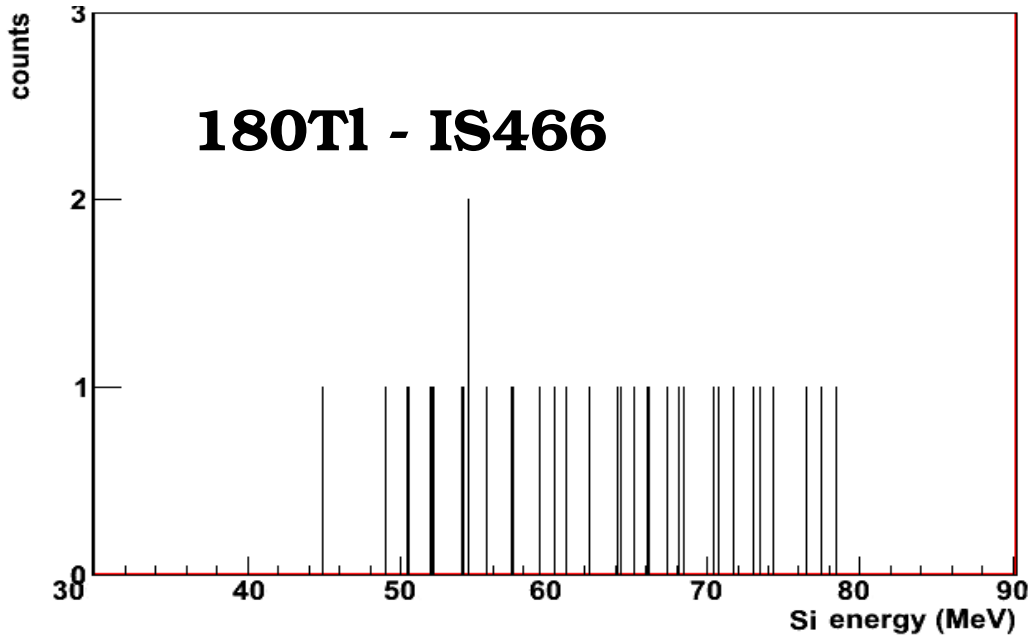




- Apparently, comparable mean width, but could be also symmetrical -
- Larger density in the middle of 202Fr in comparison with 180Tl.
- Thus, need more singles (and also need coincidences).

^{202}Fr - Fission ..





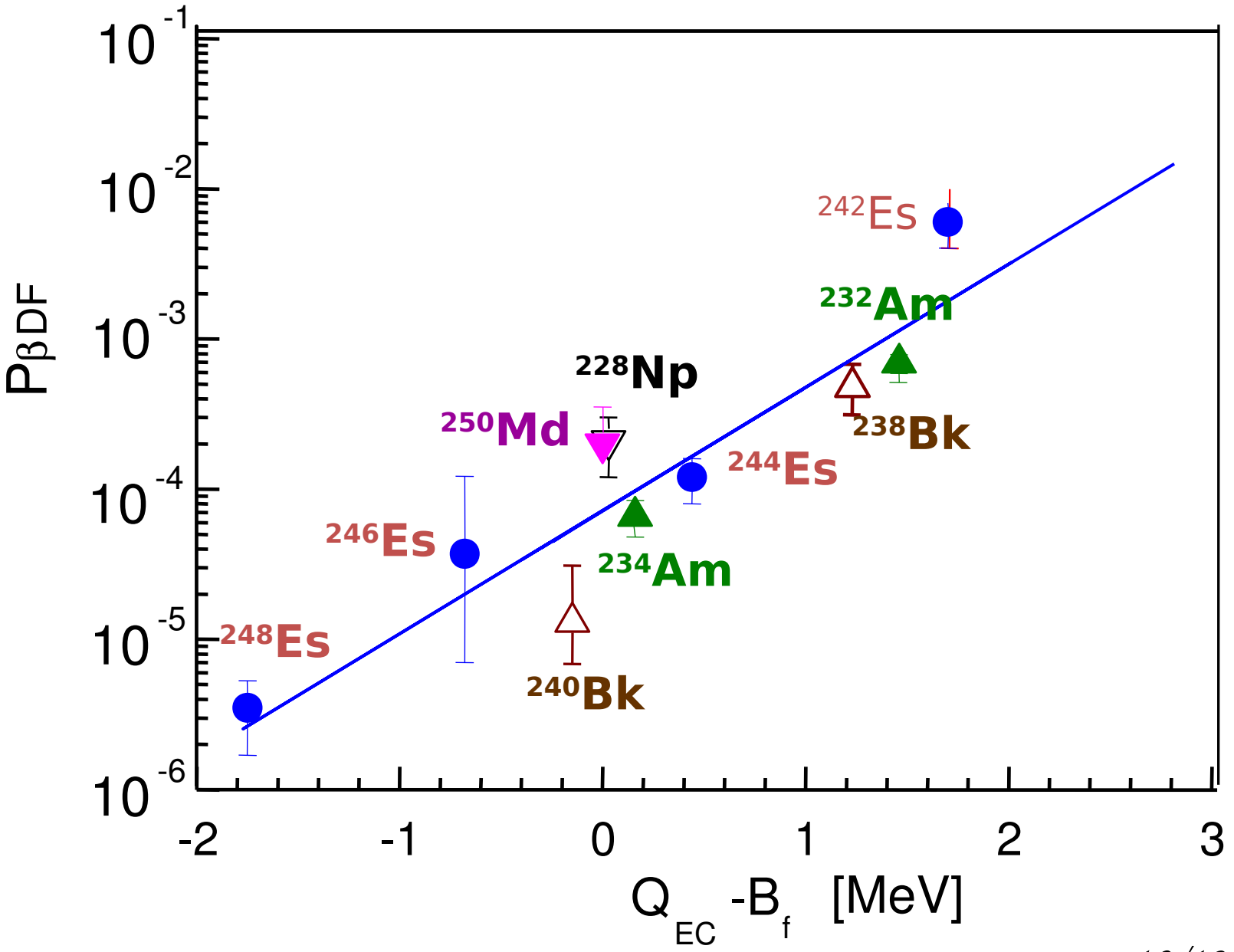
- **We need coincidence data for ^{202}Fr OR 4-5 times more statistics in singles(which is achievable)!!!!**

PRELIMINARY

$$P_{\beta DF} = 3(1)\times10^{-4}$$

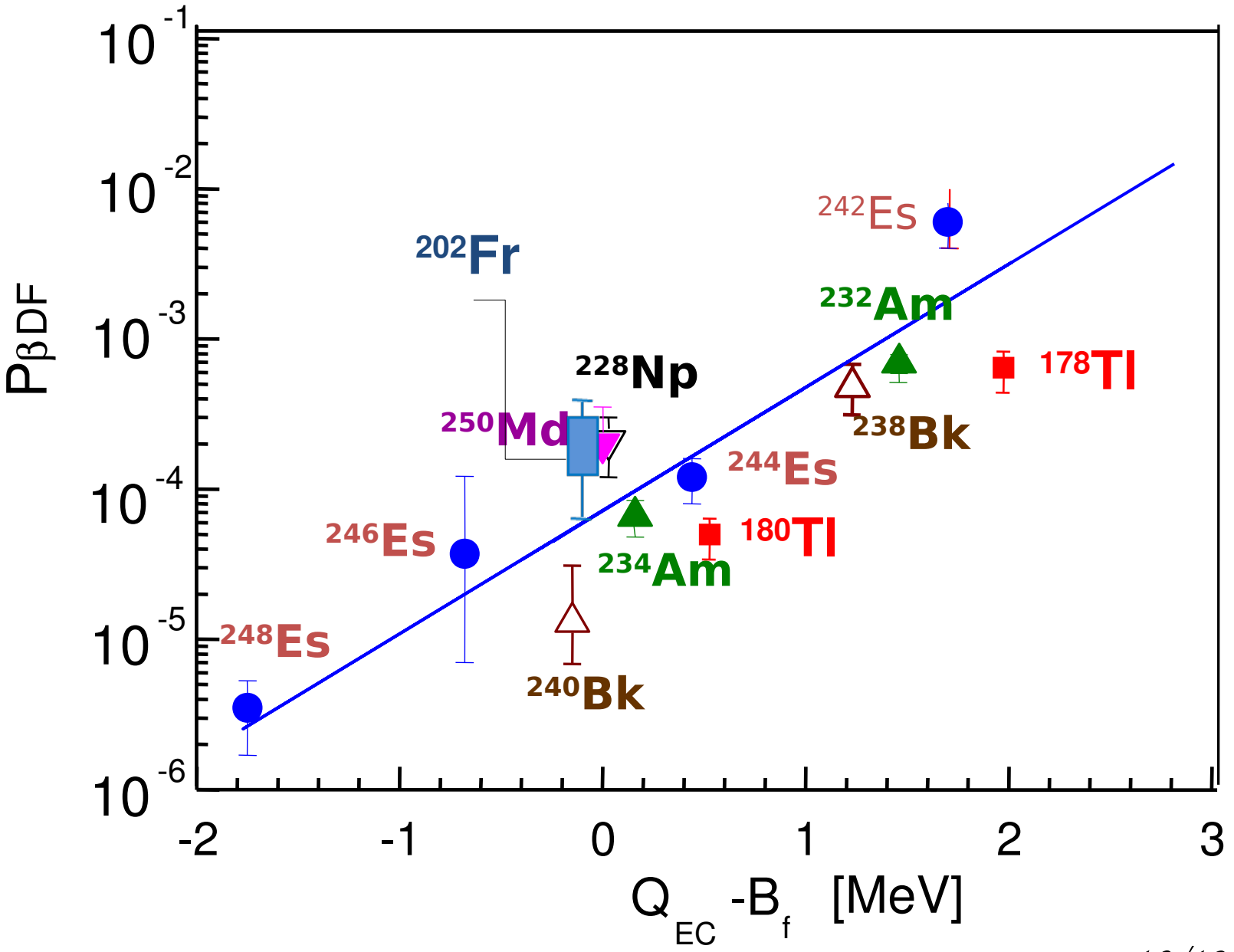
$P_{\beta DF}$ ..

- 10 known βDF cases in trans-U region
- Relatively low Q_{EC} and B_f values (3-5 MeV)
- **Linear dependence**



P_{BDF} ..

- Pb-region data fit in the general trend.
- Before IS466 two different behaviours were expected for PBDF in the U- and Pb-regions (different Q and B_f)
- **SAME behaviour observed!!**



bDF@GSI

- @ **ISOLDE**:
  - implanted low-energy beam in C foil, surrounded by Si detectors
  - measured mass distributions and, with some procedures – branching ratios (but need to know the properties of daughter products, not always the case)

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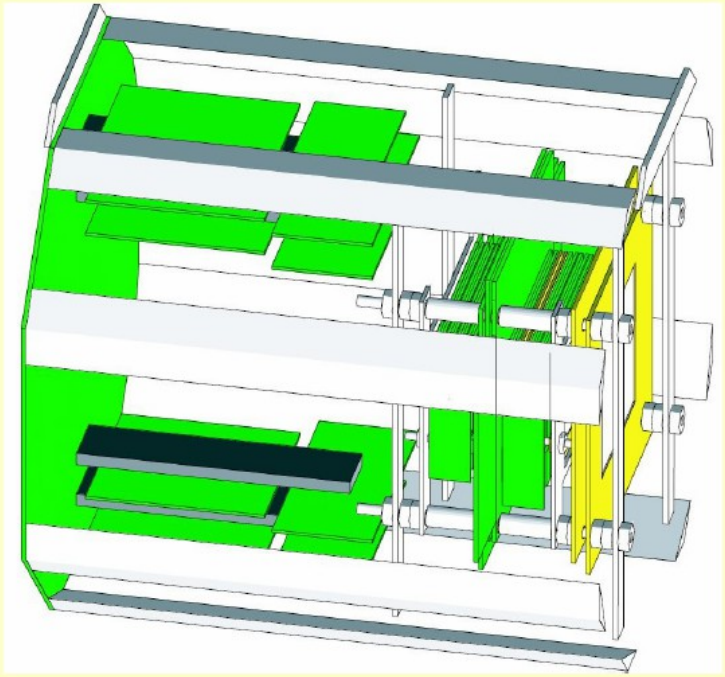
- @ **FRS/Super FRS**:
  - we will implant the nuclei in a stack of Si detectors
  - we measure
    - Branching ratio (simply by counting number of implants and number of fission decays) provided beta-branch is known (or measure) **Advantage of FRS** – deep implantation, no recoil effects, 100% efficiency
    - TKE measurements (due to deep implantation in Si, no losses, no partial ff escapes)
    - possibility to identify fission fragments via their gamma decay (high gamma efficiency)

bDF@GSI..possible setup?

Similar to that, used to study ^{100}Sn

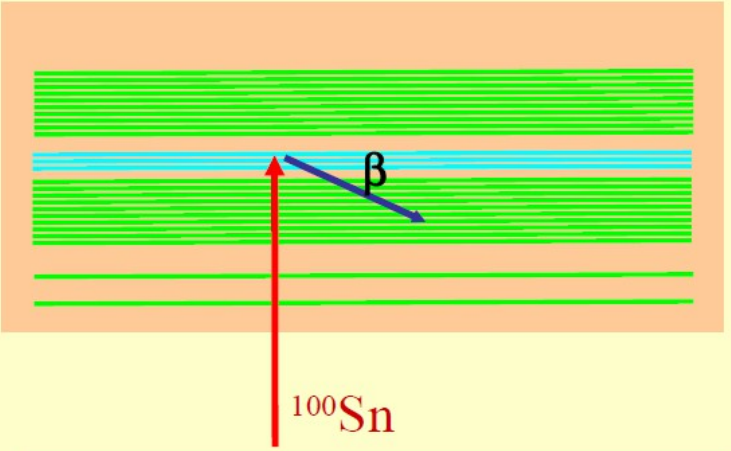
Silicon Implantation Detectorand Beta Absorber SIMBA

Lehrstuhl E12



7 x-strips

10 SSSD 60x40x1 mm³	single channel readout
3 DSSD 60x40x0.7 mm³	
10 SSSD 60x40x1 mm³	
Y SSSD 60x60x0.3 mm³	R - chain
X SSSD 60x60x0.3 mm³	



pixels in implantation zone:
3x60x40 = 7200

bDF@GSI..possible setup?

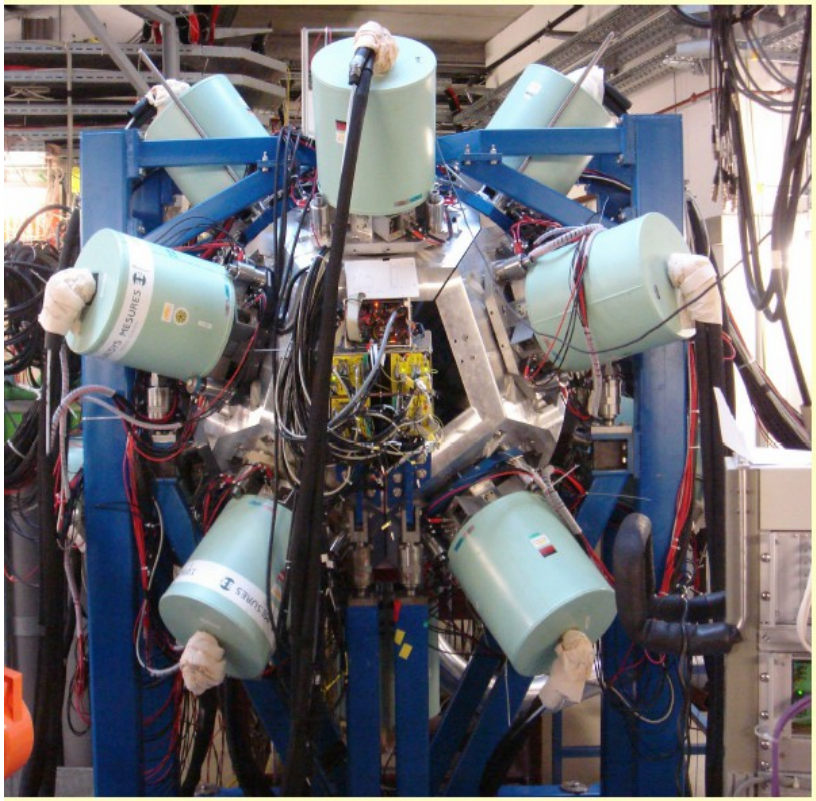
Gamma Detection

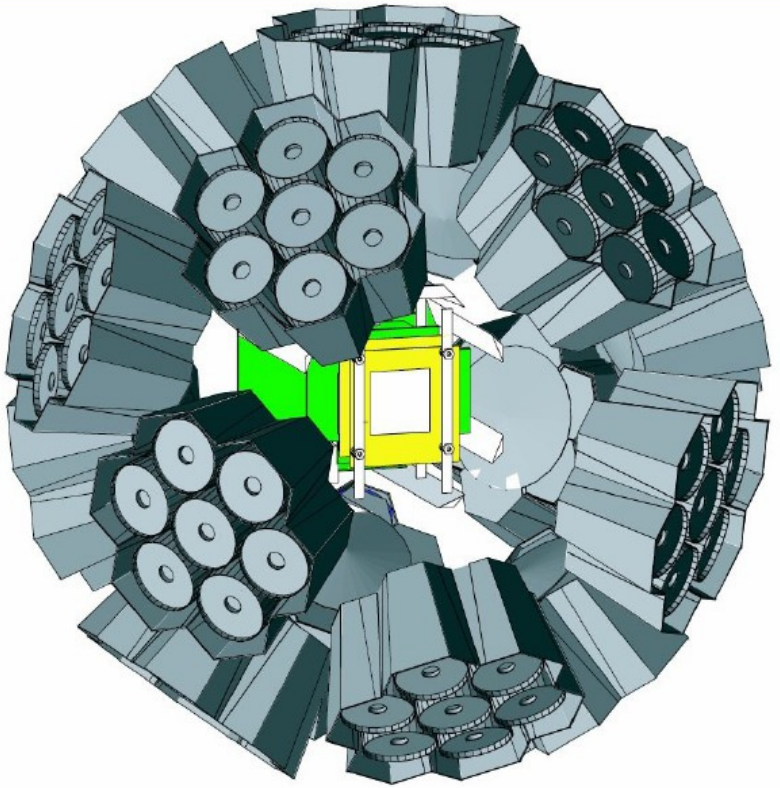
Lehrstuhl E12

RISING

15 x 7 Germanium detectors

ε_{Photo} ~ 15% @667keV





Collaboration ..

UNIVERSITY OF THE WEST of SCOTLAND

Andrei Andreyev
Valentina Liberati
Joseph Lane

Los Alamos NATIONAL LABORATORY

P. Möller, A. Sierk

ISOLDE CERN

RILIS & ISOLDE

IKS KATHOLIEKE UNIVERSITEIT LEUVEN

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Thomas Cocolios
Jan Diriken
Jytte Elseviers
Mark Huyse
Paul Van den Bergh
Piet Van Duppen
Martin Venhart
D. Radulov
Hilde De Witte
I. Darby

RIKEN
Takatoshi Ichikawa

JAEA

Katsuhisa Nishio
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S. Vermote, C. Wagemans (*University of Gent, Belgium*)
M. Veselský (*Slovak Academy of Sciences, Bratislava, Slovakia*)

Thank you
For the attention

Future Work and Analysis in the Pb region ..

Identification of new bDF nuclei and detailed studies (e.g. Bf, TKE, mass..)

ISOLDE:

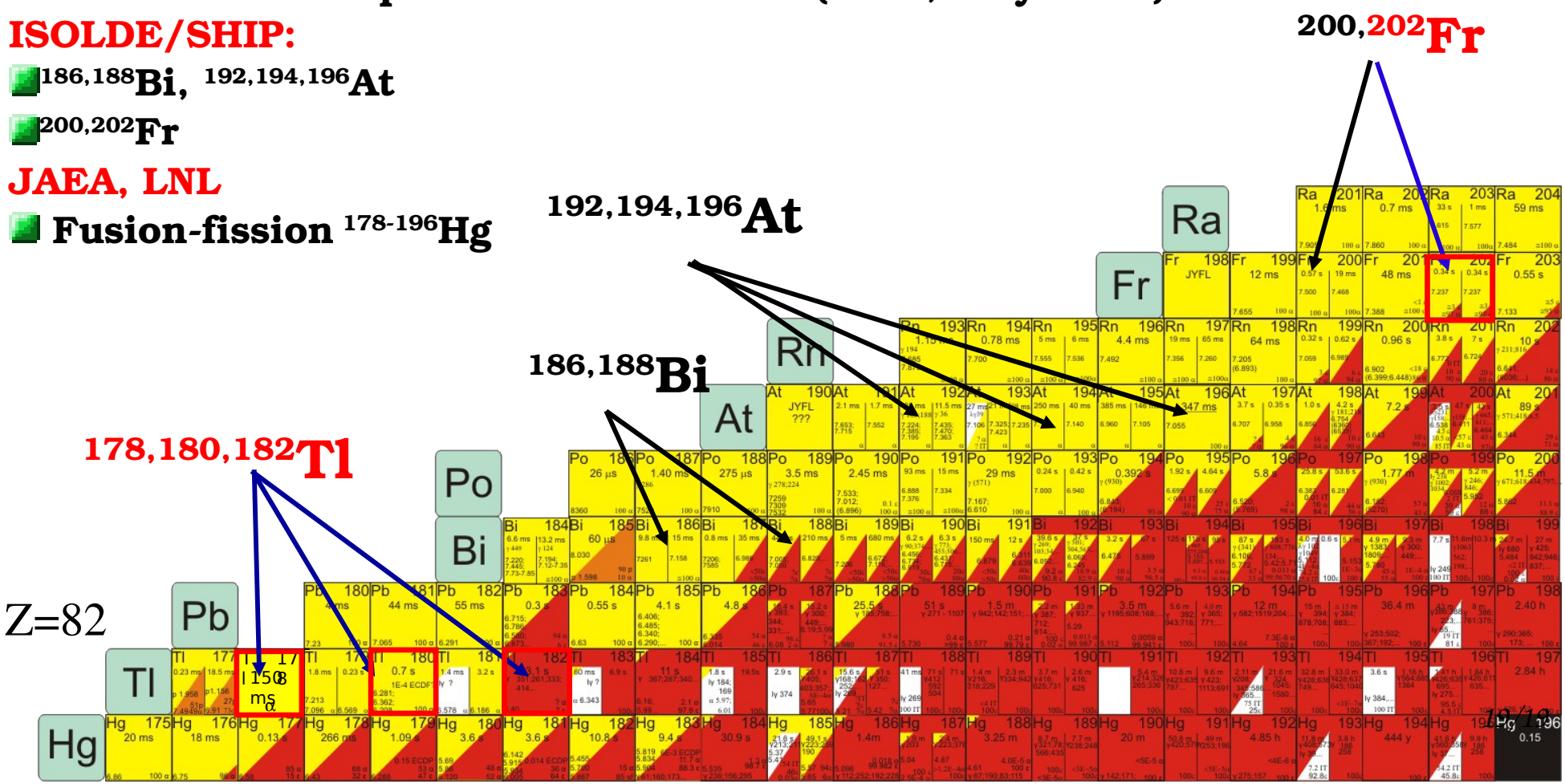
- **^{180}Tl – HFS scan with RILIS : search for 2 isomeric states**
- **^{180}Tl – mass measurement at ISOLTRAP**
- **^{178,182}Tl – bDF experiments at ISOLDE (done, July 2010)**

ISOLDE/SHIP:

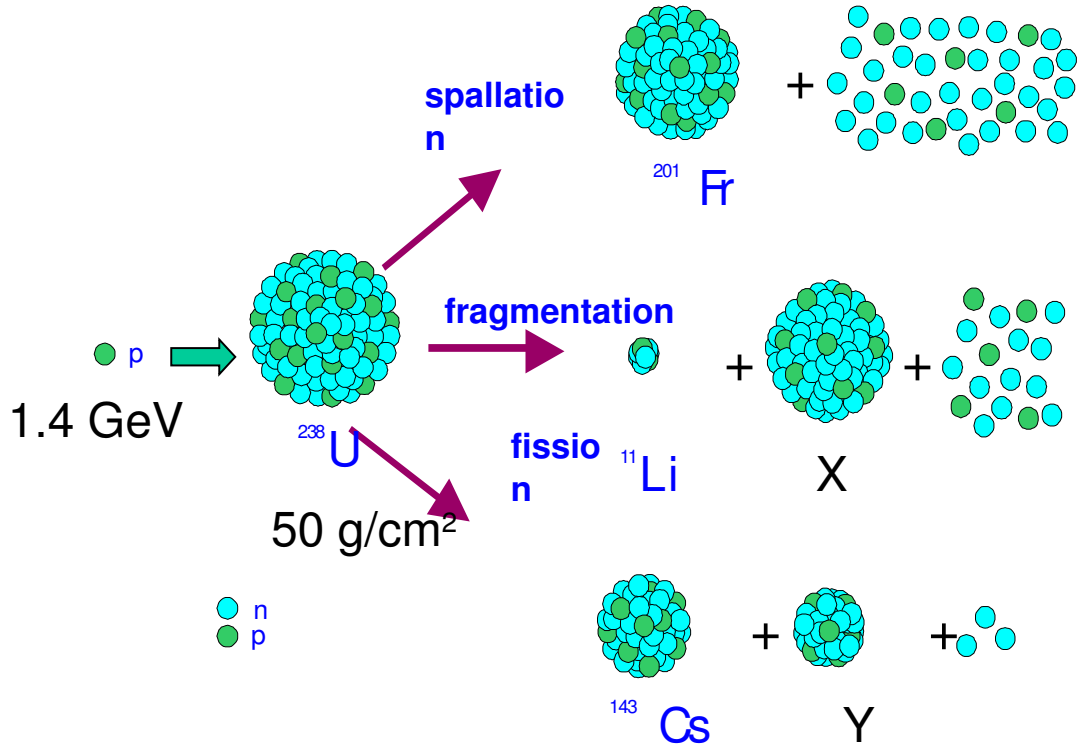
- **^{186,188}Bi, ^{192,194,196}At**
- **^{200,202}Fr**

JAEA, LNL

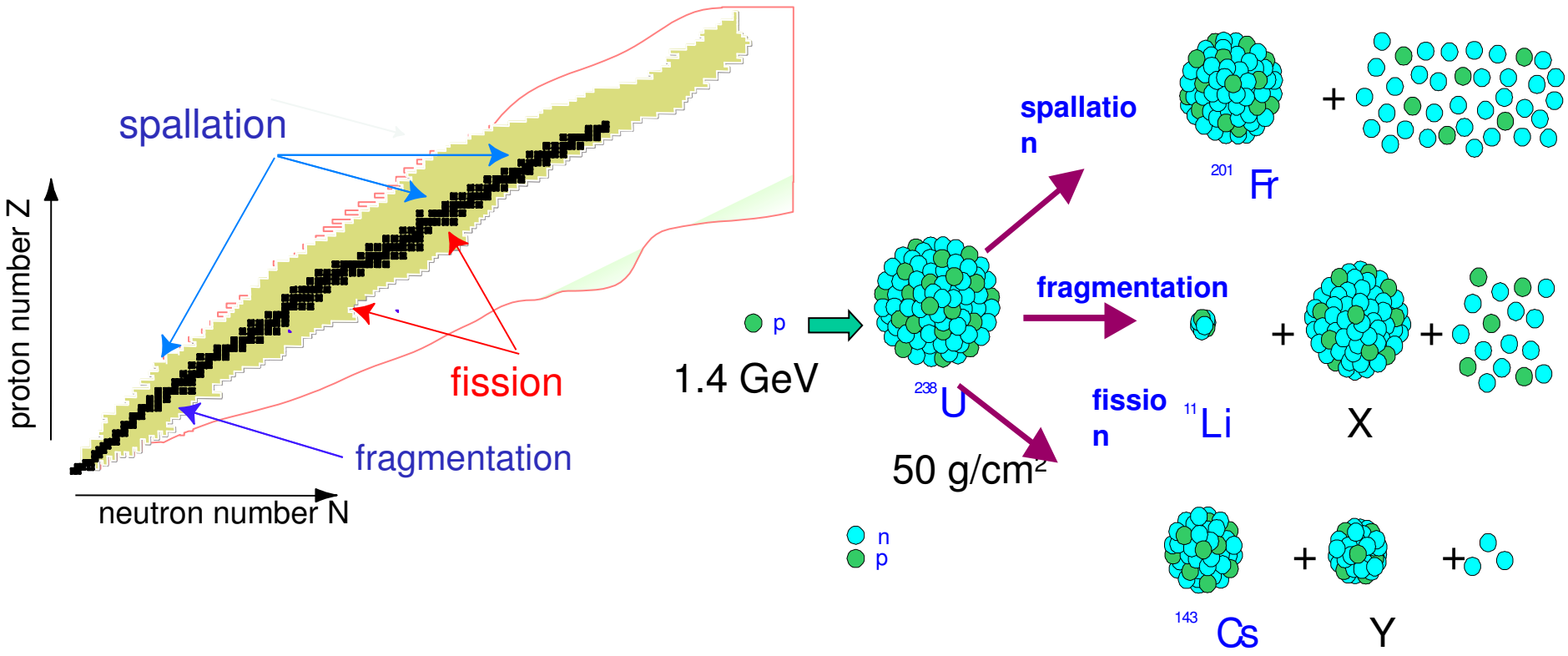
- **Fusion-fission $^{178\text{-}196}$Hg**



Radioactive Isotope production..

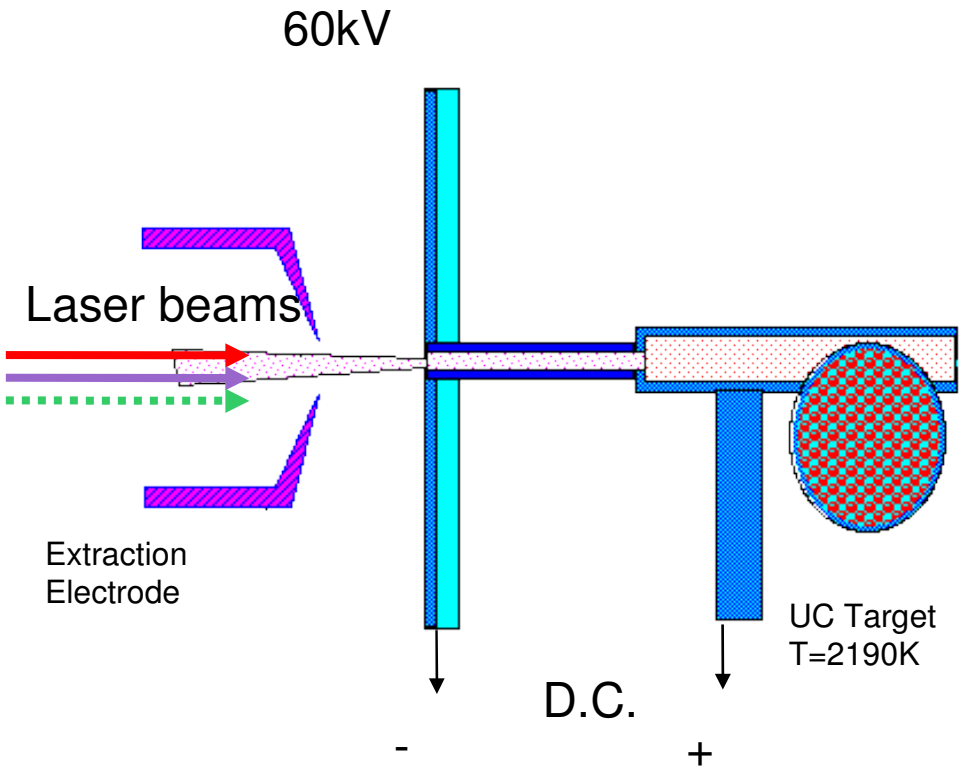


Radioactive Isotope production..

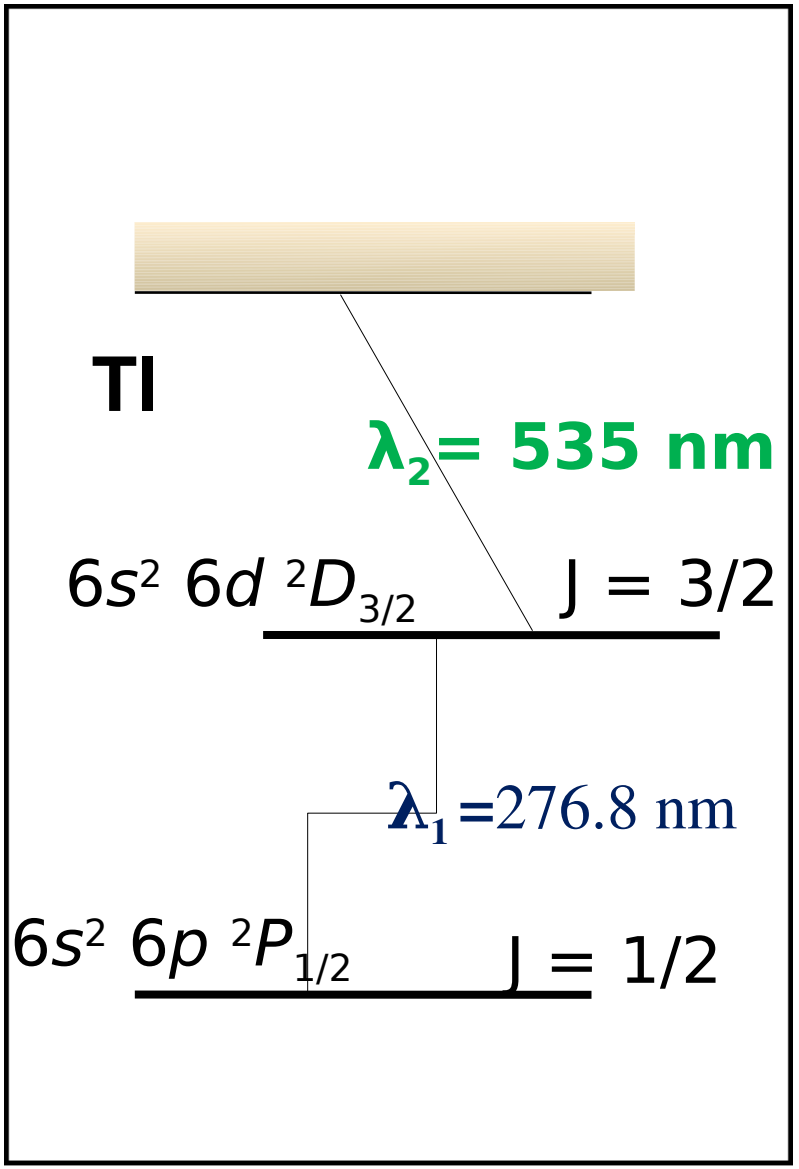


The target material is chosen to maximise the desired isotope production

RILIS ..



- Highly selective process, ε = 2%-19%
- It uses lasers of different wavelength to stepwise ionize a specific element

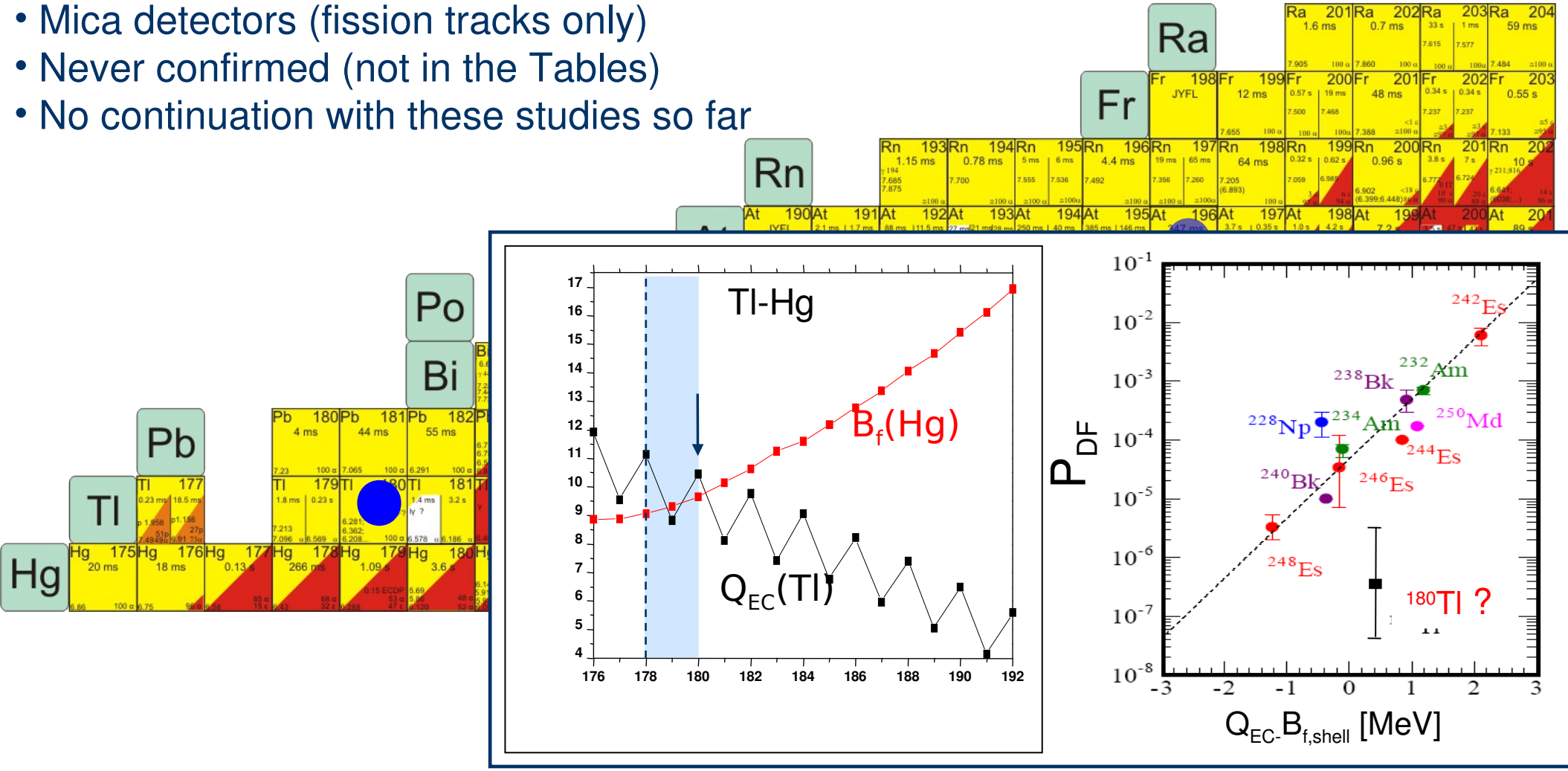


Previous Studies in the Pb region (Dubna)

Yu. A. Lazarev et al. Europhys. Lett. 4 (1987) 893; and Inst. Phys. Conf. Ser. No132 (1992) 739

"Most probable" candidates: ^{180}Tl ($P_{ECDF}=3\times 10^{-(7\pm1)}$), ^{188}Bi,^{196}At (no P_{ECDF} data)

- Irradiations inside the cyclotron (no A,Z selection for products)
- Rotating wheel system, thick effective targets (2 mg/cm^2)
- Cross-irradiations, apparent σ_{fis}~15-50 pb
- Mica detectors (fission tracks only)
- Never confirmed (not in the Tables)
- No continuation with these studies so far



A bit of IS ..

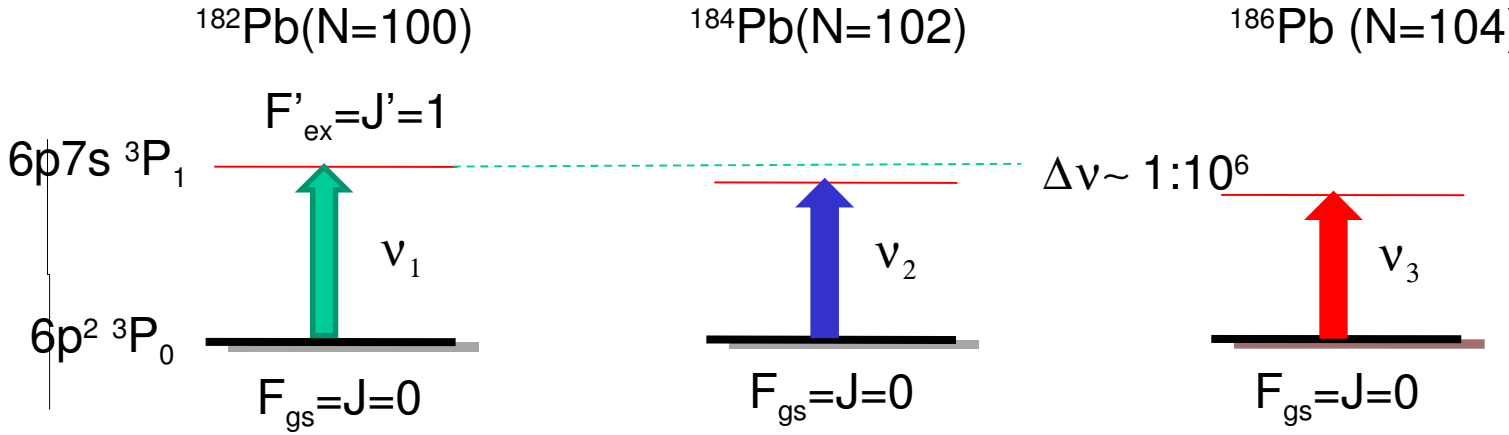
$\Delta\nu = \nu_1 - \nu_2$ Isotope Shift (IS)

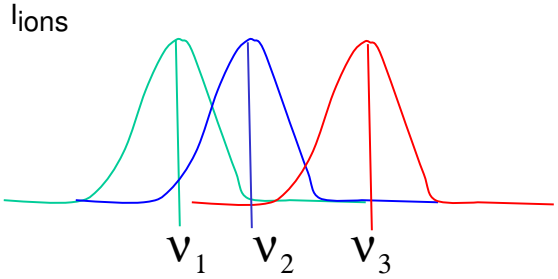
Total Angular Momentum of an Atom

$F_{atom} = I_{nuclear} + J_{electron}$

(for an even-even isotope I=0, thus, F=J)

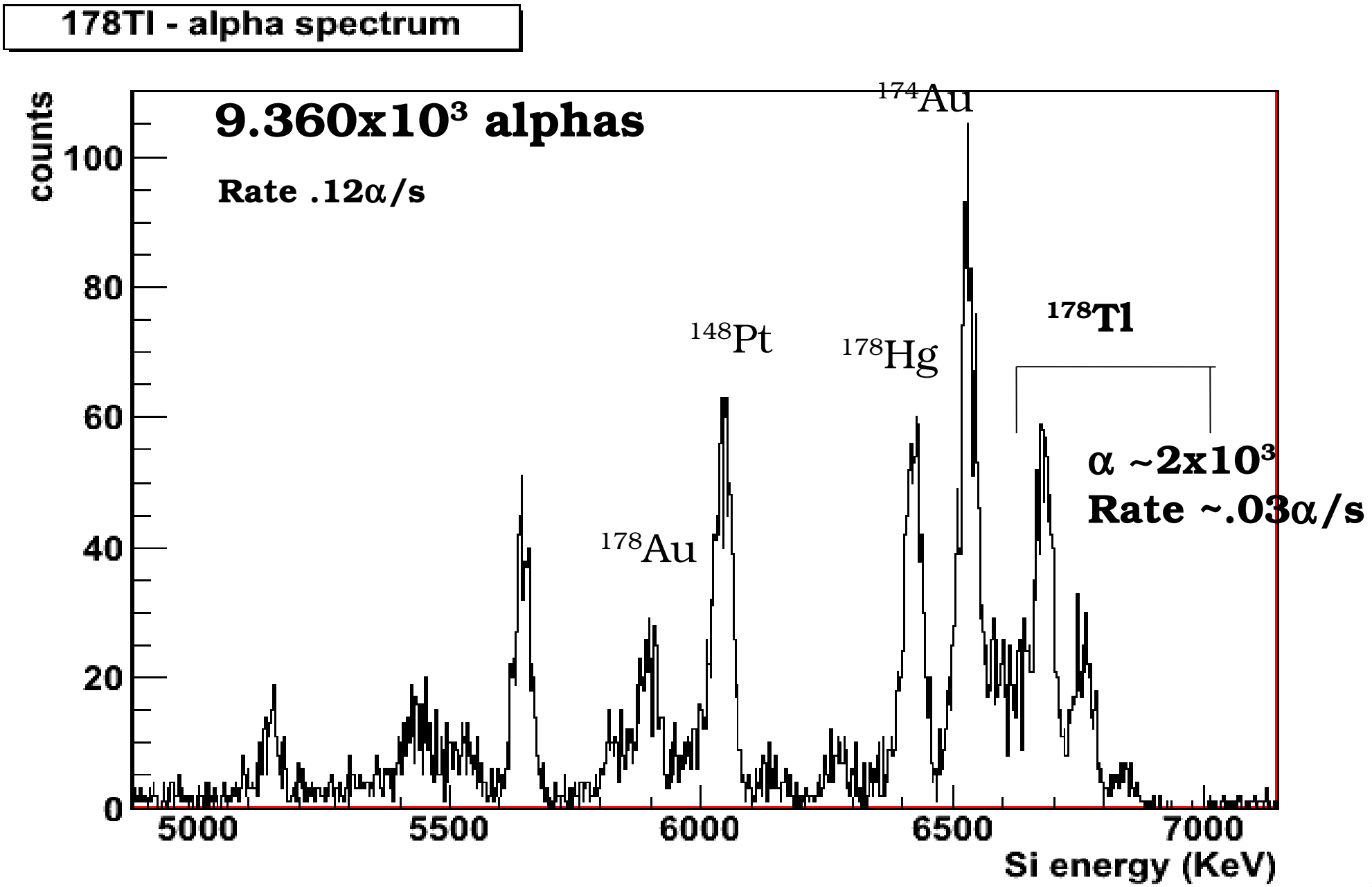
Let's consider, e.g. even-even Pb (Z=82) isotopes





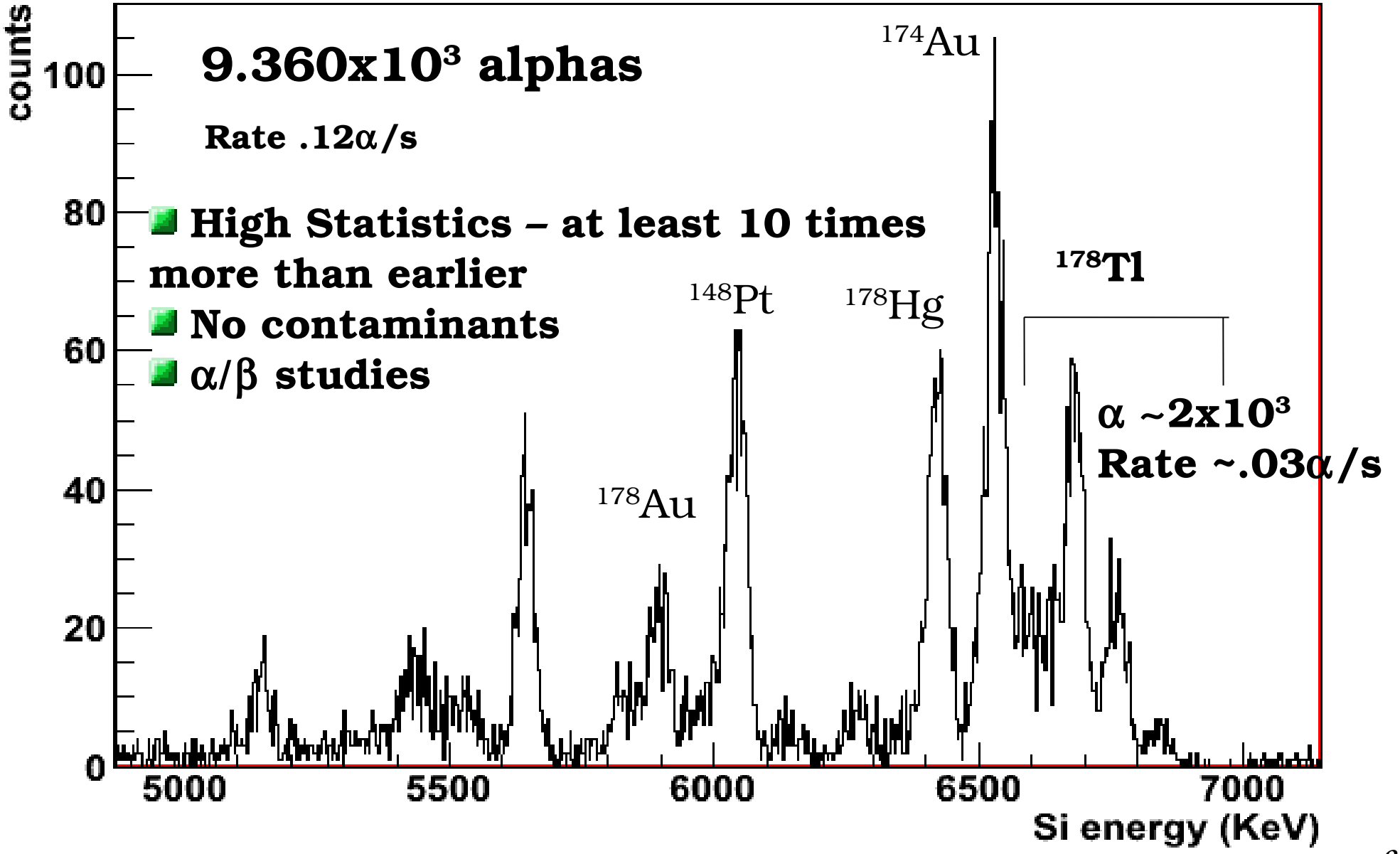
IS proportional to the charge radius!

^{178}Tl ..

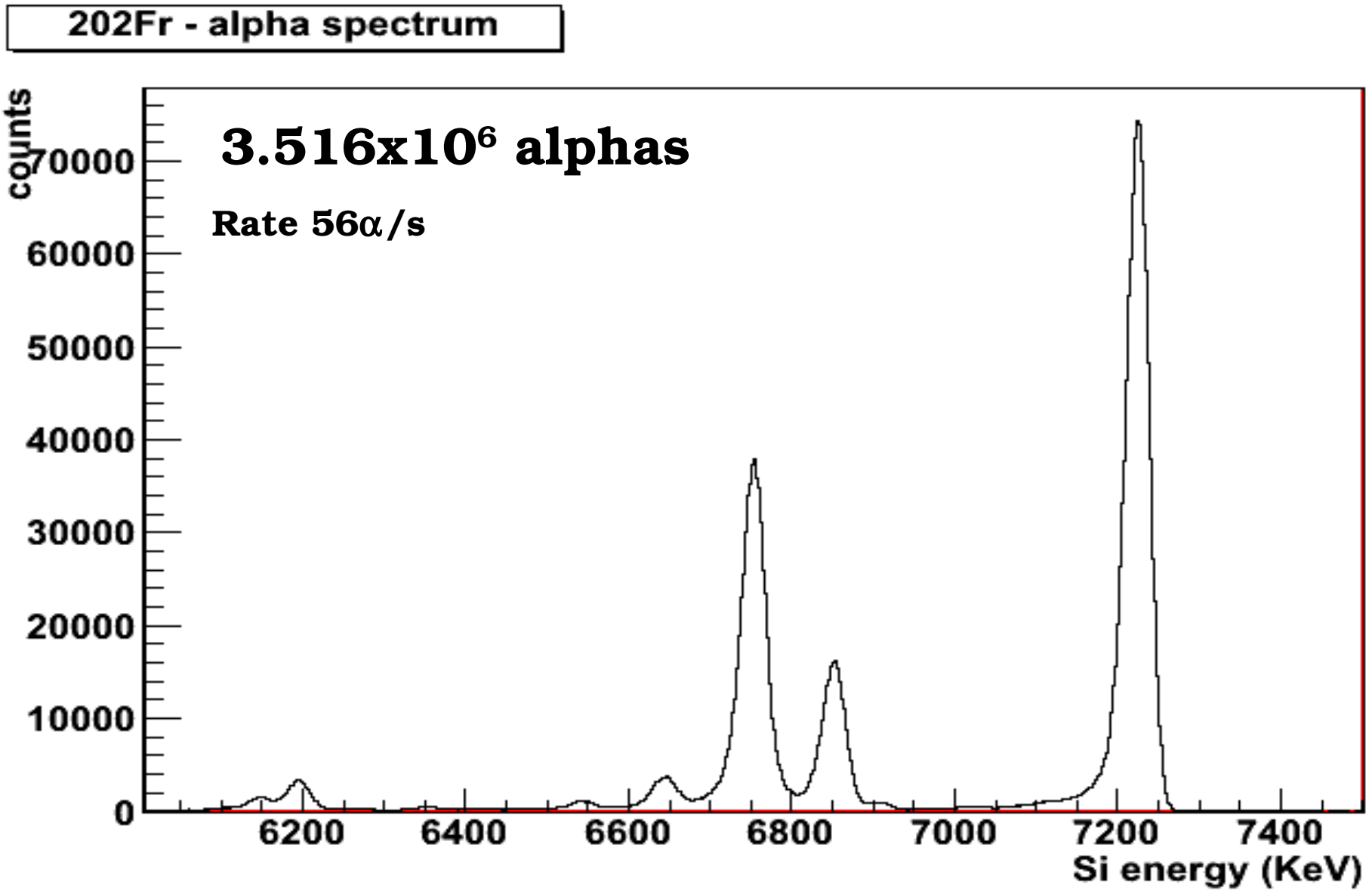

178Tl - alpha spectrum
9.360x10³ alphas
Rate .12α/s
counts
100
80
60
40
20
0
5000
5500
6000
6500
7000
Si energy (KeV)
174Au
148Pt
178Hg
178Tl
178Au
α ~2x10³
Rate ~.03α/s

^{178}Tl ..

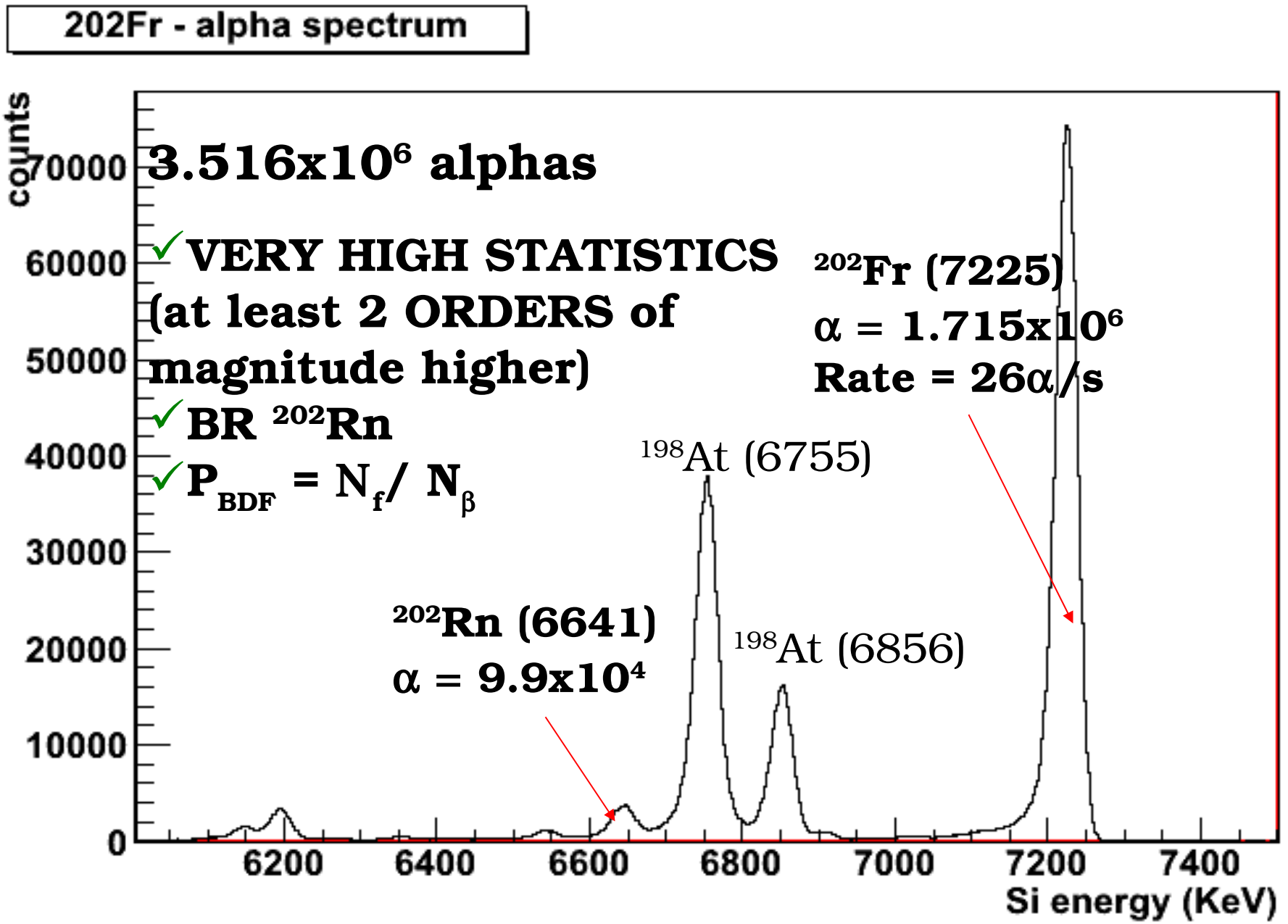
178Tl - alpha spectrum



^{202}Fr ..


202Fr - alpha spectrum
3.516x10⁶ alphas
Rate 56α/s
counts
70000
60000
50000
40000
30000
20000
10000
0
6200
6400
6600
6800
7000
7200
7400
Si energy (KeV)

^{202}Fr ..


202Fr - alpha spectrum
counts
70000
60000
50000
40000
30000
20000
10000
0
6200
6400
6600
6800
7000
7200
7400
Si energy (KeV)
3.516x10⁶ alphas
✓VERY HIGH STATISTICS (at least 2 ORDERS of magnitude higher)
✓BR ²⁰²Rn
✓P_BDF = N_f/ N_β
²⁰²Fr (7225)
α = 1.715x10⁶
Rate = 26α/s
¹⁹⁸At (6755)
¹⁹⁸At (6856)
²⁰²Rn (6641)
α = 9.9x10⁴